910 Intersections At Grade

910.01 General

Intersections are a critical part of highway design because of increased conflict potential. Traffic and driver characteristics, bicycle and pedestrian needs, physical features, and economics are considered during the design stage to develop channelization and traffic control to enhance safeand efficient multimodal traffic flow throughintersections.

This chapter provides guidance for designing intersections at grade, including at-grade ramp terminals. Guidelines for road approaches are in Chapter920 and interchanges are in Chapter940.

If an intersection design situation is not covered in this chapter, contact the Olympic Service Center (OSC) Design Office, for assistance.

910.02 References

Americans with Disabilities Act of 1990 (ADA)

Washington Administrative Code (WAC) 468-18-040, “Design standards for rearranged county roads, frontage roads, access roads, intersections, ramps and crossings”

WAC 468-52, “Highway access management—Access control classification system and standards”

Local Agency Guidelines (LAG), M 36-63, WSDOT

Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), USDOT, FHWA; including the *Washington State Modifications to the MUTCD*, M 24-01, WSDOT

Standard Plans for Road, Bridge, and Municipal Construction (Standard Plans), M 21-01, WSDOT

Roundabouts: An Informational Guide, FHWA-RD-00-067, USDOT, FHWA

A Policy on Geometric Design of Highways and Streets (Green Book), AASHTO

Highway Capacity Manual (HCM), Special Report 209, Transportation Research Board, National Research Council

NCHRP 279
Intersection Channelization Design Guide

Highway Research Record No. 211
Aspects of Traffic Control Devices, pp 1-18, “Volume Warrants for Left-Turn Storage Lanesat Unsignalized Grade Intersections.” Harmelink, M. D.

910.03 Definitions

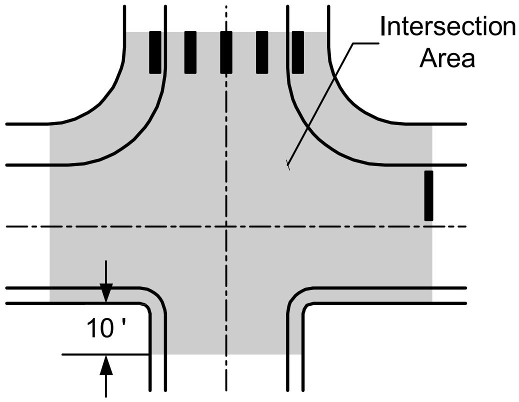
bulb out A curb and sidewalk bulge or extension out into the roadway used to decrease the length of a pedestrian crossing. (See chapter 1025.)

conflict An event involving two or more road users, in which the action of one user causes the other user to make an evasive maneuver to avoid a collision.

crossroad The minor roadway at an intersection. At a stopped controlled intersection, the crossroad has the stop.

intersection angle The angle between any two <u>intersecting</u> legs at the point that the center lines intersect.

intersection area The area of the intersecting roadways bounded by the edge of traveled ways and the area of the adjacent roadways to the end of the corner radii, any marked crosswalks adjacent to the intersection, or stop bar, but not less than 10 ft from the edge of shoulder of the intersecting roadway.



intersection at grade The general area where a state route or ramp terminal is met or crossed at a common grade or elevation by another state route, a county road, or a city street.

four leg intersection An intersection with four legs, as where two highways cross.

tee (T) intersection An intersection with three legs in the general form of a "T."

split tee A four leg intersection with the cross road intersecting the through roadway at two tee intersections. The crossroad must be offset at least the width of the roadway.

wye (Y) intersection An intersection with three legs in the general form of a "Y" and the angle between two legs is less than 60°.

intersection leg Any one of the roadways radiating from and forming part of an intersection.

entrance leg The lanes of an intersection leg for traffic entering the intersection.

exit leg The lanes of an intersection leg for traffic leaving the intersection.

Whether an intersection leg is an entrance leg or an exit leg depends on which movement is being analyzed. For two way roadways, each leg is an entrance leg for some movements and an exit leg for other movements.

intersection sight distance The distance that the driver of a vehicle on the crossroad can see along the through roadway, as compared to the distance required for safe operation.

intersection turning radii The geometric design of the intersection to allow the design vehicle for each turning movement to complete the turn without encroachment.

island A defined area within an intersection, between traffic lanes, for the separation of vehicle movements or for pedestrian refuge. It may be outlined with pavement markings or delineated by curbs. Within an intersection, a median is considered an island.

channelization island An island that separates traffic movements into definite paths of travel and guides traffic into the intended route.

divisional island An island introduced, on an undivided roadway, at an intersection to warn drivers of the crossroad ahead and regulate traffic through the intersection.

refuge island An island at or near a crosswalk or bicycle path to aid and protect pedestrians and bicyclists crossing the roadway.

median crossover An opening in a median provided for crossings by maintenance, law enforcement, emergency, and traffic service vehicles. (See Chapter 960.)

roundabout A circular intersection at which all traffic moves counterclockwise around a central island. (See Chapter 915)

rural intersection An intersection in a nonurban area.

urban intersection An intersection that is in one of the following areas:

- The area within the federal urban area boundary as designated by FHWA.
- An area characterized by intensive use of the land for the location of structures and receiving such urban services as sewers, water, and other public utilities and services normally associated with urbanized areas.
- An area with not more than twenty-five percent undeveloped land.

910.04 Design Considerations

Intersection design requires consideration of all potential users of the facility. This involves addressing the needs of a diverse mix of user groups including passenger cars, heavy vehicles of varying classifications, bicycles, and pedestrians. Often, meeting the needs of one user group requires a compromise in service to others. Intersection design balances these competing needs, resulting in appropriate levels of operation for all users.

In addition to reducing the number of conflicts, minimize the conflict area as much as possible while still providing for the required design vehicle (910.05). This is done to control the speed of turning vehicles and reduce vehicle, bicyclist, and pedestrian exposure.

(1) Traffic Analysis

Conduct a traffic analysis and an accident analysis to determine the design characteristics of each intersection. Include recommendations for channelization, turn lanes, acceleration and deceleration lanes, intersection configurations, illumination, bicycle and pedestrian accommodations, ADA requirements, and traffic control devices in the traffic analysis.

(2) Intersection Configurations

(a) **Intersection angle.** An important intersection design characteristic is the intersection angle. The allowable intersection angles are 75° to 105° for new, reconstructed, or realigned intersections.

Existing intersections with an intersection angle between 60° and 120° may remain. Intersection angles outside this range tend to restrict visibility, increase the area required for turning, increase the difficulty to make a turn, increase the crossing distance and time for vehicles and pedestrians, and make traffic signal arms difficult or impossible to design.

(b) **Lane alignment.** Design intersections with entrance lanes aligned with the exit lanes. Do not put angle points on the roadway alignments within intersection areas or on the through roadway alignment within 100 ft of the edge of traveled way of a crossroad. This includes short radius curves where both the PC and PT are within the intersection area. However, angle points within the intersection are allowed at intersections with a minor through movement, such as at a ramp terminal (Figure 910-19).

When practical, locate intersections so that curves do not begin or end within the intersection area.

(c) **Split Tee.** Avoid split tee intersections where there is less than the intersection spacing for the Highway Access Management Class. See 910.04(4). Split tee intersections with an offset distance to the left greater than the width of the roadway, but less than the intersection spacing, may be designed with justification. Evaluate the anticipated benefits against the increased difficulty in driving through the intersection and a more complicated traffic signal design.

Split tee intersections with the offset to the right have the additional disadvantages of overlapping left-turns, increased possibility of wrong way movements, and traffic signal design that is even more complicated. Do not design a split tee intersection with an offset to the right less than the intersection spacing for the class unless traffic is restricted to right-in right-out only.

(d) **Other Nonstandard Configurations.** Do not design intersections with nonstandard configurations such as:

- Intersections with offset legs.
- Intersections with more than four legs.
- Tee intersections with the major traffic movement making a turn.
- Wye intersections that are not a one-way merge or diverge.

A roundabout may be an alternative to these nonstandard configurations. (See 910.08 and Chapter 915.)

(3) Crossroads

When the crossroad is a city street or county road, design the crossroad crossroad beyond the intersection area according to the applicable standards shown in:

- Chapter 468-18 WAC.
- The LAG manual.

- The standards of the local agency that will be requested to accept the facility.

When the crossroad is a state facility, design the crossroad according to the applicable design level and functional class (Chapters 325, 430, and 440). Continue the cross slope of the through roadway shoulder as the grade for the crossroad. Use a vertical curve that is at least 60 ft long to connect to the grade of the crossroad.

In areas that experience accumulations of snow and ice and for all legs that will require traffic to stop, design a maximum grade of ±4 percent for a length equal to the anticipated queue length for stopped vehicles.

(4) Intersection Spacing

Adequate intersection spacing is required to provide for safety and the desired operational characteristics for the highway. Provide enough space between intersections for left-turn lanes and storage length. Space signalized intersections, and intersections expected to be signalized, to maintain efficient signal operation. It is desirable to space intersections so that queues will not block an adjacent intersection.

The minimum spacing for highways with limited access control is covered in Chapter 1420. For other highways, the minimum spacing is dependent on the Highway Access Management Class. Figure 910-1 gives the minimum spacing between intersections for each Highway Access Management Class.

Highway Access Management Class	Intersection Spacing (mi)
1	1
2	1/2
3[1]	1/2
4[1]	1/2
5[1]	1/4

[1]Spacing is for rural intersections and urban intersections that might require signalization.

Minimum Intersection Spacing
Figure 910-1

A deviation for less than the minimum spacing in Figure 910-1 will be considered only when no reasonable alternative access exists. For Class 1 highways, intersection spacing less than 1/2 mi is not permitted (WAC 468-52-040).

910.05 Design Vehicle

The physical characteristics of the design vehicle control the geometric design of the intersection. The following design vehicle types are commonly used:

Design Symbol	Vehicle Type
P	Passenger car, including light delivery trucks.
BUS	Single unit bus
A-BUS	Articulated bus
SU	Single unit truck
WB-40	Semitrailer truck, overall wheelbase of 40 ft
WB-50	Semitrailer truck, overall wheelbase of 50 ft
WB-67	Semitrailer truck, overall wheelbase of 67 ft
MH	Motor home
P/T	Passenger car pulling a camper trailer
MH/B	Motor home pulling a boat trailer

Design Vehicle Types
Figure 910-2

The geometric design of an intersection requires identifying and addressing the needs of all intersection users. There are competing design objectives when considering the turning requirements of the larger design vehicles and the crossing requirements of pedestrians. To reduce the operational impacts of large design vehicles, turn radii are designed so that large vehicles can complete their turn without encroaching on the adjacent lanes at either the entrance or the exit legs of the turn. This results in larger radii that causes increased pavement areas, longer pedestrian crossing distances, and longer traffic signal arms.

To reduce the intersection area, a smaller design vehicle is used or encroachment on the adjacent same direction lanes at exit legs of the turn is allowed. This reduces the potential for vehicle/pedestrian conflicts, decreases pedestrian crossing distance, and controls speeds of turning vehicles. The negative impacts include capacity reductions and greater speed differences between turning vehicles and through vehicles.

Select a design vehicle that is the largest vehicle that normally uses the intersection. The primary use of the design vehicle is to determine turning radius requirements for each leg of the intersection. It is possible for each leg to have a different design vehicle. Figure 910-3 shows the minimum design vehicles. As justification to use a smaller vehicle, include a traffic analysis showing that the proposed vehicle is appropriate.

Intersection Type	Design Vehicle
Junction of Major Truck Routes	WB-67
Junction of State Routes	WB-50
Ramp Terminals	WB-50
Other Rural	WB-50
Industrial	WB-40
Commercial	SU(1)(2)
Residential	SU(1)(2)

(1)To accommodate pedestrians, the P vehicle may be used as the design vehicle if justification, with a traffic analysis, is documented.

(2)When the intersection is on a transit or school bus route, use the BUS design vehicle as a minimum. See Chapter 1060 for additional guidance for transit facilities.

Intersection Design Vehicle
Figure 910-3

To minimize the disruption to other traffic, design the intersection to allow the design vehicles to make each turning movement without encroaching on curbs, opposing lanes, or same-direction lanes at the entrance leg. Use turning path templates (Figures 910-7a through 7c or templates from another published source) to verify that the design vehicle can make the turning movements.

Encroachment on same-direction lanes of the exit leg and the shoulder might be necessary to minimize crosswalk distances; however, this might negatively impact vehicular operations. Document and justify the operational tradeoffs associated with this encroachment. When encroachment on the shoulder is required, increase the pavement structure to support the anticipated traffic.

Design each turning movement so the largest vehicle that is anticipated to occasionally use the intersection can make the turn without leaving the paved shoulders or encroaching on a sidewalk. Use the WB-67 as the largest vehicle at all state route to state route junctions. Document and justify any required encroachment into other lanes, and any degradation of intersection operation.

910.06 Right-Turn Corners

The geometric design of an intersection requires identifying and addressing the needs of all intersection users. For the design of right turn corners, there can be competing design objectives when considering the turning requirements of the design vehicle and the crossing requirements of pedestrians. To reduce the operational impacts of large trucks, right-turn radii are designed so that the truck can complete its turn without encroaching on the adjacent lanes at either the entrance or the exit legs of the turn. This results in larger corner radii, increased pavement area and pedestrian crossing distance, a larger conflict area, and higher vehicle turning speeds.

When pedestrian issues are a primary concern, the design objectives become one of reducing the potential for vehicle/pedestrian conflicts. This is done by minimizing pedestrian crossing distance and controlling speeds of turning vehicles. This normally leads to right-corner designs with smaller turning radii. The negative impacts include capacity reductions and greater speed differences between turning vehicles and through vehicles.

Pedestrian refuge islands can also improve pedestrian safety. Pedestrian refuge islands minimize the crossing distance, reduce the conflict area, and minimize the impacts on vehicular traffic. When designing islands, speeds can be reduced by designing the turning roadway with a taper or large radius curve at the beginning of the turn and a small radius curve at the end. This allows larger islands while forcing the turning traffic to slow down.

Figure 910-8 shows right-turn corner designs for the design vehicles. These are considered the minimum pavement area to accommodate the design vehicles without encroachment on the adjacent lane at either leg of the curve.

With justification, right-turn corner designs given in Figure 910-8 may be modified. Document the benefits and impacts of the modified design including: changes to vehicle pedestrian conflicts, vehicle encroachment on the shoulder or adjacent same direction lane at the exit leg, capacity restrictions for right-turning vehicles or other degradation of intersection operations, and the effects on other traffic movements. To verify that the design vehicle can make the turn, include a plot of the design showing the design vehicle turning path template.

910.07 Channelization

Channelization is the separation or regulation of traffic movements into delineated paths of travel to facilitate the safe and orderly movement of vehicles, bicycles, and pedestrians.

Painted or plastic pavement markings are normally used to delineate travel paths. (See Chapter 830 and the standard plans for details.)

(1) Left-Turn Lanes

Left-turn lanes provide storage, separate from the through lanes, for left-turning vehicles waiting for a signal to change or for a gap in opposing traffic. (See 910.07(3) for a discussion on speed change lanes.)

Design left-turn channelization to provide sufficient operational flexibility to function under peak loads and adverse conditions.

(a) **One-Way Left-Turn Lanes** are separate storage lanes for vehicles turning left from one roadway onto another. When recommended, one-way left-turn lanes may be an economical way to lessen delays and accident potential involving left-turning vehicles. In addition, they can allow deceleration clear of the through traffic lanes. When considering left-turn lanes, consider impacts to all intersection movements and users.

At signalized intersections, use a traffic signal analysis to determine if a left-turn lane is needed and what the storage requirements are. (See Chapter 850.)

At unsignalized intersections, use the following as a guide to determine whether or not to provide one-way left-turn lanes:

- A traffic analysis indicates that a left-turn lane will reduce congestion. On two-lane highways, use Figure 910-9a, based on total traffic volume (DHV) for both directions and percent left-turn traffic, to determine if further investigation is needed. On four-lane highways, use Figure 910-9b to determine if a left-turn lane is recommended.
- An accident study indicates that a left-turn lane will reduce accidents.
- Restrictive geometrics require left-turning vehicles to slow greatly below the speed of the through traffic.
- There is less than decision sight distance at the approach to the intersection.

An HCM analysis may also be used to determine if left-turn lanes are necessary to maintain the desired level of service.

Determine the storage length required on two-lane highways by using Figures 910-10a through 10c. On four-lane highways use Figure 910-9b. These lengths do not consider trucks. Use Figure 910-4 for storage length when trucks are present.

Storage* Length (ft)	% Trucks in Left-Turn Movement				
	10	20	30	40	50
100	125	125	150	150	150
150	175	200	200	200	200
200	225	250	275	300	300
250	275	300	325	350	375
300	350	375	400	400	400

*Length from Figures 910-9b, 10a, 10b, or 10c.

Left-Turn Storage With Trucks (ft)
Figure 910-4

Design opposing left-turn vehicle paths with a minimum 4 ft clearance between opposing turning paths.

Where one-way left-turn channelization with curbing is to be provided, ensure that surface water will drain.

Provide illumination at left-turn lanes in accordance with the guidelines in Chapter 840.

At signalized intersections with high left-turn volumes, double left-turn lanes may be needed to maintain the desired level of service. A throat width of 30 to 36 ft is desirable on the exit leg of the turn to offset vehicle offtracking and the difficulty of two vehicles turning abreast. Use turning path templates to verify that the design vehicle can complete the turn. Where the design vehicle is a WB-40 or larger and the truck volumes are low, consider providing for the design vehicle and an SU turning abreast rather than two design vehicles turning abreast.

Figures 910-11a through 11d show one-way left-turn geometrics. Figure 910-11a shows widening to accommodate the new lane. Figures 910-11b and 11c show the use of a median.

1. **Widening (Figure 910-11a).** It is desirable that offsets and pavement widening be symmetrical about the center line or base line. Where right of way or topographic restrictions, crossroad alignments, or other circumstances preclude symmetrical widening, pavement widening may be on one side only.

2. **Divided Highways (Figure 910-11b and 11c).** Widening is not required for left-turn lane channelization where medians are 13 ft wide or wider. The median acceleration lane shown on the figures can also be provided where the median is 23 ft or wider. The median acceleration lane might not be necessary at a signalized intersection. When a median acceleration lane is to be used, design it in accordance with 910.07(3) Speed Change Lanes.

At intersections on divided highways where channelized left turn lanes are not provided, consider a minimum protected storage area as shown on Figure 910-11d.

(b) **Two-Way Left-Turn Lanes** (TWLTL) are located between opposing lanes of traffic. They are used by vehicles making left turns from either direction, either from or onto the roadway.

Use TWLTLs only in an urban setting where there are no more than two through lanes in each direction. Consider installation of TWLTLs where:

- An accident study indicates that a TWLTL will reduce accidents.
- There are closely spaced access points or minor street intersections.
- There are unacceptable through traffic delays or capacity reductions because of left turning vehicles.

TWLTL can reduce delays to through traffic, reduce rear-end accidents, and provide separation between opposing lanes of traffic. However, they do not provide a safe refuge for pedestrians, can create problems with closely spaced access points, and can encourage strip development with closely spaced access points. Consider other alternatives, before using TWLTL, such as prohibiting midblock left-turns and providing for U-turns.

The basic design for a TWLTL is illustrated on Figure 910-11e. Additional criteria are:

- The desirable length of a TWLTL is not less than 250 ft.

- Provide illumination in accordance with the guidelines in Chapter 840.
- Pavement markings, signs, and other traffic control devices must be in accordance with the MUTCD and the Standard Plans.
- Provide clear channelization when changing from TWLTL to one-way left-turn lanes at an intersection.

(2) Right-Turn Lanes and Drop Lanes

Right-turn movements influence intersection capacity even though there is no conflict between right-turning vehicles and opposing traffic. Right-turn lanes might be needed to maintain efficient intersection operation. Use the following as guidelines to determine when to consider right-turn lanes:

- Recommendation from Figure 910-12 based on same direction approach and right-turn traffic volumes.
- An accident study indicates that a right-turn lane will result in an overall accident reduction.
- Presence of pedestrians who require right-turning vehicles to stop in the through lanes.
- Restrictive geometrics that require right-turning vehicles to slow greatly below the speed of the through traffic.
- Less than decision sight distance at the approach to the intersection.

For unsignalized intersections, see 910.07(3) Speed Change Lanes for guidance on right-turn lane lengths. For signalized intersections, use a traffic signal analysis to determine if a right-turn lane is needed and the length requirement. (See Chapter 850.)

A capacity analysis may be used to determine if right-turn lanes are necessary to maintain the desired level of service.

When designing right-turn lanes at signalized intersections, consider reducing the shoulder width to not more than 4 ft. This reduces the pavement widening for the turn lane and removes the temptation for vehicles to use the shoulder to bypass the other vehicles in the turn lane.

Where adequate right of way exists, providing right-turn lanes is relatively inexpensive and can provide increased safety and operational efficiency.

The right-turn pocket or the right-turn taper (Figure 910-13) may be used at any minor intersection where a deceleration lane is not required and turning volumes indicate a need as set forth in Figure 910-12. These designs will cause less interference and delay to the through movement by offering an earlier exit to right-turning vehicles.

If the right-turn pocket is used, Figure 910-13 shows taper lengths for various posted speeds.

A lane may be dropped at an intersection with a turn-only lane or beyond the intersection with an acceleration lane (Figure 910-15.) Do not allow a lane-reduction taper to cross an intersection or end less than 100 ft before an intersection.

When a lane is dropped beyond a signalized intersection, provide a lane of sufficient length to allow smooth merging. For facilities with a posted speed of 45 mph or higher, use a minimum length of 1500 ft. For facilities with a posted speed less than 45 mph, provide a lane of sufficient length so that the advanced lane reduction warning sign will be placed not less than 100 ft beyond the intersection area.

(3) Speed Change Lanes

A speed change lane is an auxiliary lane primarily for the acceleration or deceleration of vehicles entering or leaving the through traveled way. Speed change lanes are normally provided for at-grade intersections on multilane divided highways with access control. Where roadside conditions and right of way allow, speed change lanes may be provided on other through roadways. Justification for a speed change lane depends on many factors such as speed, traffic volumes, capacity, type of highway, the design and frequency of intersections, and accident history.

A deceleration lane is advantageous because, if a deceleration lane is not provided the driver leaving the highway must slow down in the through lane regardless of following traffic.

An acceleration lane is not as advantageous because entering drivers can wait for an opportunity to merge without disrupting through traffic.

When either deceleration or acceleration lanes are to be used, design them in accordance with Figures 910-14 and 15. When the design speed of the turning traffic is greater than 20 mph, design the speed change lane as a ramp in accordance with Chapter 940. When a deceleration lane is used with a left-turn lane, add the deceleration length to the storage length.

(4) Islands

An island is a defined area within an intersection between traffic lanes for the separation of vehicle movements or for pedestrian refuge. Within an intersection, a median is considered an island. Design islands to clearly delineate the traffic channels to drivers and pedestrians.

Traffic islands perform these functions:

- Channelization islands control and direct traffic movement.
- Divisional islands separate traffic movements.
- Refuge islands provide refuge for pedestrians.
- Islands can provide for the placement of traffic control devices and luminaires.
- Islands can provide areas within the roadway for landscaping.

(a) **Size and Shape.** Divisional and refuge islands are normally elongated and at least 4 ft wide and 20 ft long. (Mountable curb, used to discourage turn movements, is not a divisional island.)

Channelization islands are normally triangular. In rural areas, 75 ft^2 is the minimum island area and 100 ft^2 is desirable. In urban areas where posted speeds are 25 mph or less, smaller islands are acceptable. Use islands with at least 200 ft^2 if pedestrians will be crossing or traffic control devices or luminaires will be installed.

Design triangular shaped islands as shown on Figure 910-16a through 16c. The shoulder and offset widths illustrated are for islands with barrier curbs. Where painted islands are used, such as in rural areas, these widths are desirable but may be omitted.

Avoid shoulders wider than 6 ft at islands because the wider shoulders can appear to be another lane.

Island markings may be supplemented with reflective raised pavement markers.

Barrier-free access must be provided at crosswalk locations where raised islands are used. See Chapter 1025.

(b) **Location.** Design the approach ends of islands to provide adequate visibility to alert the motorist of their presence. Position the island so that a smooth transition in vehicle speed and direction is attained. Begin transverse lane shifts far enough in advance of the intersection to allow gradual transitions. Avoid introducing islands on a horizontal or vertical curve. If the use of an island on a curve cannot be avoided, provide adequate sight distance, illumination, or extension of the island.

(c) **Compound Right-Turn Lane.** To design large islands, the common method is to use a large radius curve for the turning traffic. While this does provide a larger island, it also encourages higher turning speeds. Where pedestrians are a concern, higher turning speeds are undesirable. An alternative is a compound curve with a large radius followed by a small radius (Figure 910-16c). This design forces the turning traffic to slow down.

(d) **Curbing.** Provide barrier curb for:

- Islands with luminaires, signals, or other traffic control devices.
- Pedestrian refuge islands.

In addition consider curbing for:

- Divisional and channelizing islands.
- Landscaped islands.

Avoid using curbs if the same objective can be attained with pavement markings.

Where curbing is to be provided, ensure that surface water will drain.

Snow removal operations can be hampered by curbs and raised islands. Contact the region's Operations Engineer when considering raised channelization in areas of heavy snowfall.

In general, neither mountable nor barrier curbs are used on facilities with a posted speed of 45 mph or greater.

910.08 Roundabouts

Modern roundabouts are circular intersections. They can be an effective intersection type.

Modern roundabouts differ from the old rotaries and traffic circles in two important respects: they have a smaller diameter, which lowers speeds; and they have splitter islands that provide entry constraints, slowing down the entering speeds.

When well designed, roundabouts are an efficient form of intersection control. They have fewer conflict points, lower speeds, easier decision making, and they require less maintenance. When properly designed and located, they have been found to reduce injury accidents, traffic delays, fuel consumption, and air pollution. Roundabouts also permit U-turns.

Consider roundabouts at intersections with the following characteristics:

- Where stop signs result in unacceptable delays for the crossroad traffic. Roundabouts reduce the delays for the cross road, but increase the delays for the through roadway.
- With a high left-turn percentage. Unlike most intersection types, roundabouts can operate efficiently with high volumes of left-turning traffic.
- With more than four legs. When the intersection cannot be modified by closing or relocating legs, a roundabout can provide a solution.
- Where a disproportionately high number of accidents involve crossing or turning traffic.
- Where the major traffic movement makes a turn.
- Where traffic growth is expected to be high and future traffic patterns are uncertain.
- Where it is not desirable to give priority to either roadway.

There are some disadvantages with roundabouts. Roundabouts do not allow for a primary roadway to have priority because all legs entering a roundabout are treated the same. Also, all traffic entering a roundabout is required to reduce speed. Therefore, roundabouts are not appropriate on high speed facilities, where traffic flows are unbalanced, or where an arterial intersects a collector or local road.

See Chapter 915 for information and requirements on the design of roundabouts.

910.09 U-Turns

For divided highways without full access control that have access points where a median prevents left turns, consider providing locations designed to allow U-turns. Normally, the U-turn opportunities are provided at intersections; however, where intersections are spaced far apart, consider median openings between intersections to accommodate U-turns. Use the desirable U-turn spacing (Figure 910-5) as a guide to determine when to consider U-turn locations between intersections. When the U-turning volumes are low, use longer spacing.

	U-Turn Spacing	
	Desirable	**Minimum**
Urban(1)	1,000 ft	(2)
Suburban	1/2 mi	1/4 mi(3)
Rural	1 mi	1/2 mi

(1)For design speeds greater than 45 mph use suburban spacing.

(2)The minimum spacing is the acceleration lane length from a stop plus 300 ft.

(3)For design speeds greater than 50 mph, the minimum spacing is the acceleration lane length from a stop plus 300 ft.

U-Turn Spacing
Figure 910-5

When designing U-turn locations, use Figure 910-17 as a guide. Where the median is less than 40 ft wide and a large design vehicle is required, consider the use of a U-turn roadway.

Document the need for U-turn locations, the spacing used, and justify the selected design vehicle.

910.10 Sight Distance at Intersections

For traffic to move safely through intersections, drivers need to be able to see stop signs, traffic signals, and oncoming traffic in time to react accordingly.

Provide decision sight distance, where practical, in advance of stop signs, traffic signals, and roundabouts. See Chapter 650 for guidance.

The driver of a vehicle that is stopped, waiting to cross or enter a through roadway, needs obstruction-free sight triangles in order to see enough of the through roadway to safely complete all legal maneuvers before an approaching vehicle on the through roadway can reach the intersection. Use Figure 910-18a to determine minimum sight distance along the through roadway.

The sight triangle is determined as shown in Figure 910-18b. Within the sight triangle, lay back the cut slopes and remove, lower, or move hedges, trees, signs, utility poles, and anything else large enough to be a sight obstruction. Consider eliminating parking so sight distance is not obstructed.

The 18 ft from the edge of traveled way for the sight triangle in Figure 910-18b is for a vehicle 10 ft from the edge of traveled way. This is the minimum distance for the sight triangle. When the stop bar is placed more than 10 ft from the edge of traveled way, consider providing the sight triangle to a point 8 ft back of the stop bar.

Provide a clear sight triangle for a P vehicle at all intersections. In addition to this, provide a clear sight triangle for the SU vehicle for rural highway conditions. If there is significant combination truck traffic, use the WB-50 or WB-67 rather than the SU. In areas where SU or WB vehicles are minimal, and right of way restrictions prohibit adequate sight triangle clearing, only the P vehicle need be considered.

At some intersections, the turning volume from a stop-controlled crossroad is significant enough to conflict with vehicles on the through roadway. Sight distances shown on Figure 910-6 are desirable at these intersections. This is the sight distance required for a P vehicle to turn left or right onto a two-lane highway and attain average running speed without being overtaken by an approaching vehicle going the same direction at the average running speed.

Design Speed (mph)	Sight Distance (ft)
25	300
30	380
35	480
40	590
45	730
50	860
60	1,150
70	1,560

Sight Distance for Turning Vehicles
Figure 910-6

Designs for movements that cross divided highways are influenced by the median widths. If the median is wide enough to store the design vehicle, sight distances are determined in two steps. The first step is for crossing from a stopped position to the median storage; the second step is for the movement, either across, or left into the through roadway.

Design ramp terminal sight distance as for at-grade intersections with a turning movement. An added element at ramp terminals is the grade separation structure. Figure 910-18b gives the sight distance considerations in the vicinity of a structure. In addition, when the crossroad is an undercrossing, check the sight distance under the structure graphically using a truck eye height of 6 ft and an object height of 1.5 ft.

Document a brief description of the intersection area, sight distance restrictions, and traffic characteristics to support the design vehicle and sight distances chosen.

910.11 Traffic Control at Intersections

Intersection traffic control is the process of moving traffic safely through areas of potential conflict where two or more roadways meet. Signs, signals, channelization, and physical layout are the major tools used to establish intersection control.

There are three objectives to intersection traffic control that can greatly improve intersection operations.

- **Maximize Intersection Capacity.** Since two or more traffic streams cross, converge, or diverge at intersections, capacity of an intersection is normally less than the roadway between intersections. It is usually necessary to assign right of way through the use of traffic control devices to maximize capacity for all users of the intersection. Turn prohibitions may be used to increase intersection capacity.
- **Reduce Conflict Points.** The crossing, converging, and diverging of traffic creates conflicts which increase the potential for accidents involving turning vehicles. Establishing appropriate controls can reduce the possibility of two cars attempting to occupy the same space at the same time. Pedestrian accident potential can also be reduced by appropriate controls.
- **Priority of Major Streets.** Traffic on major routes is normally given the right of way over traffic on minor streets to increase intersection operational efficiency.

If a signal is being considered or exists at an intersection that is to be modified, a preliminary signal plan is required (Chapter 850). If a new signal permit is required, it must be approved before the design is approved.

A proposal to install a traffic signal or a roundabout on a state route, either NHS or Non-NHS, with a posted speed limit of 45 mph or higher requires an analysis of alternatives, approved by the region's Traffic Engineer with review and comment by the Olympia Service Center Design Office, prior to proceeding with the design. Include the following alternatives in the analysis:

- Channelization, providing deceleration lanes, storage, and acceleration lanes for left- and right-turning traffic.
- Right-off /right-on with U-turn opportunities.
- Grade separation.
- Roundabouts.
- Traffic control signals.

Include a copy of the analysis with the preliminary signal plan or roundabout justification.

910.12 Interchange Ramp Terminals

The design to be used or modified for use on one-way ramp terminals with stop or traffic signal control at the local road is shown on Figure 910-19. Higher volume intersections with multiple ramp lanes are designed individually.

Due to probable development of large traffic generators adjacent to an interchange, width for a median on the local road is desirable whenever such development is believed imminent. This allows for future left-turn channelization. Use median channelization when justified by capacity determination and analysis, or by the need to provide a smooth traffic flow.

Determine the number of lanes for each leg by capacity analysis methods assuming a traffic signal cycle, preferably 45 or 60 seconds in length, regardless of whether a signal is used or not. Consider all terminals in the analysis.

Adjust the alignment of the intersection legs to fit the traffic movements and to discourage wrong way movements. Use the allowed intersecting angles of 75° to 105° (60° to 120° for modified design level) to avoid broken back or reverse curves in the ramp alignment.

910.13 Procedures

Document design considerations and conclusions in accordance with Chapter 330. For highways with access control, see Chapter 1420 for access control requirements.

(1) Approval

An intersection is approved in accordance with Chapter 330. When required, the following items must be in the project file before an intersection may be approved:

- Traffic analysis
- Deviations approved in accordance with Chapter 330
- Preliminary traffic signal plan approved by the OSC Traffic Office. (See Chapter 850.)
- Intersections with roundabouts require OSC Design Office approval. See Chapter 915 for approval procedures.

(2) Intersection Plans

Intersection plans are required for any increases in capacity (turn lanes) of an intersection, modification of channelization, or change of intersection geometrics. Support the need for intersection or channelization modifications with history, school bus and mail route studies, hazardous materials route studies, public meeting comments, and so forth.

Include the following as applicable:

- Drawing of the intersection showing existing and new alignment of the main line and crossroad.
- Main line stationing of the intersection and angle between intersection legs.
- Curve data on main line and crossroads.
- Right of way lines.
- Location and type of channelization.
- Width of lanes and shoulders on main line and crossroads (Chapter 440 and 640).
- Proposed access control treatment (Chapter 1420).
- Traffic data including volumes for all movements and vehicle classifications.
- Classes of highway and design speeds for main line and crossroads (Chapter 440).
- Whether or not the intersection will be signalized or illuminated.
- A copy of all deviations, if any.

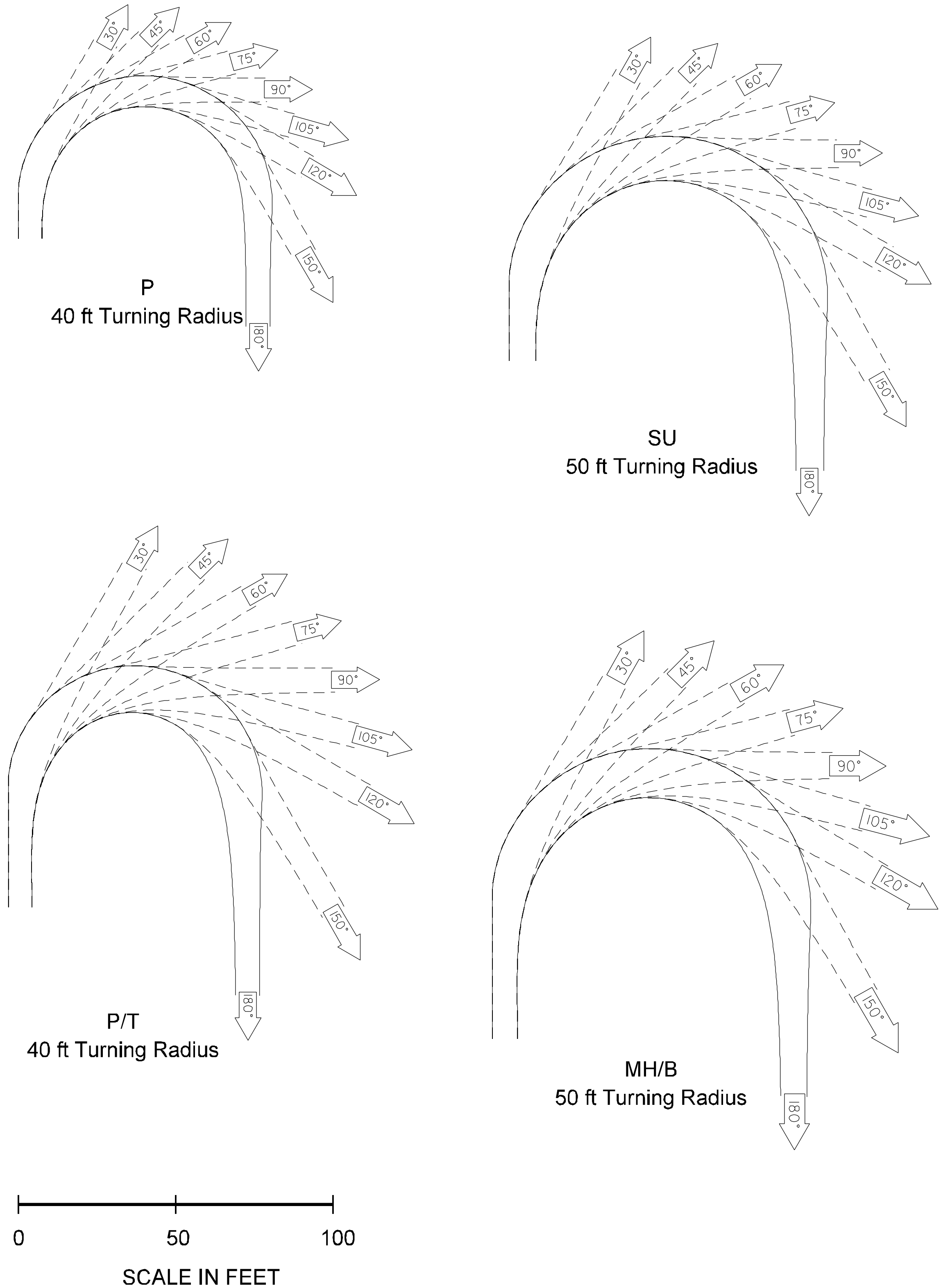
(3) Local Agency or Developer Initiated Intersections

There is a separate procedure for local agency or developer-initiated projects at intersections with state routes. The project initiator submits an intersection plan, and the documentation of design considerations that led to the plan, to the region for approval. For those plans requiring a deviation, the deviation must be approved in accordance with Chapter 330 prior to approval of the plan. After the plan approval, the region prepares a construction agreement with the project initiator. (See the *Utilities Manual*.)

910.14 Documentation

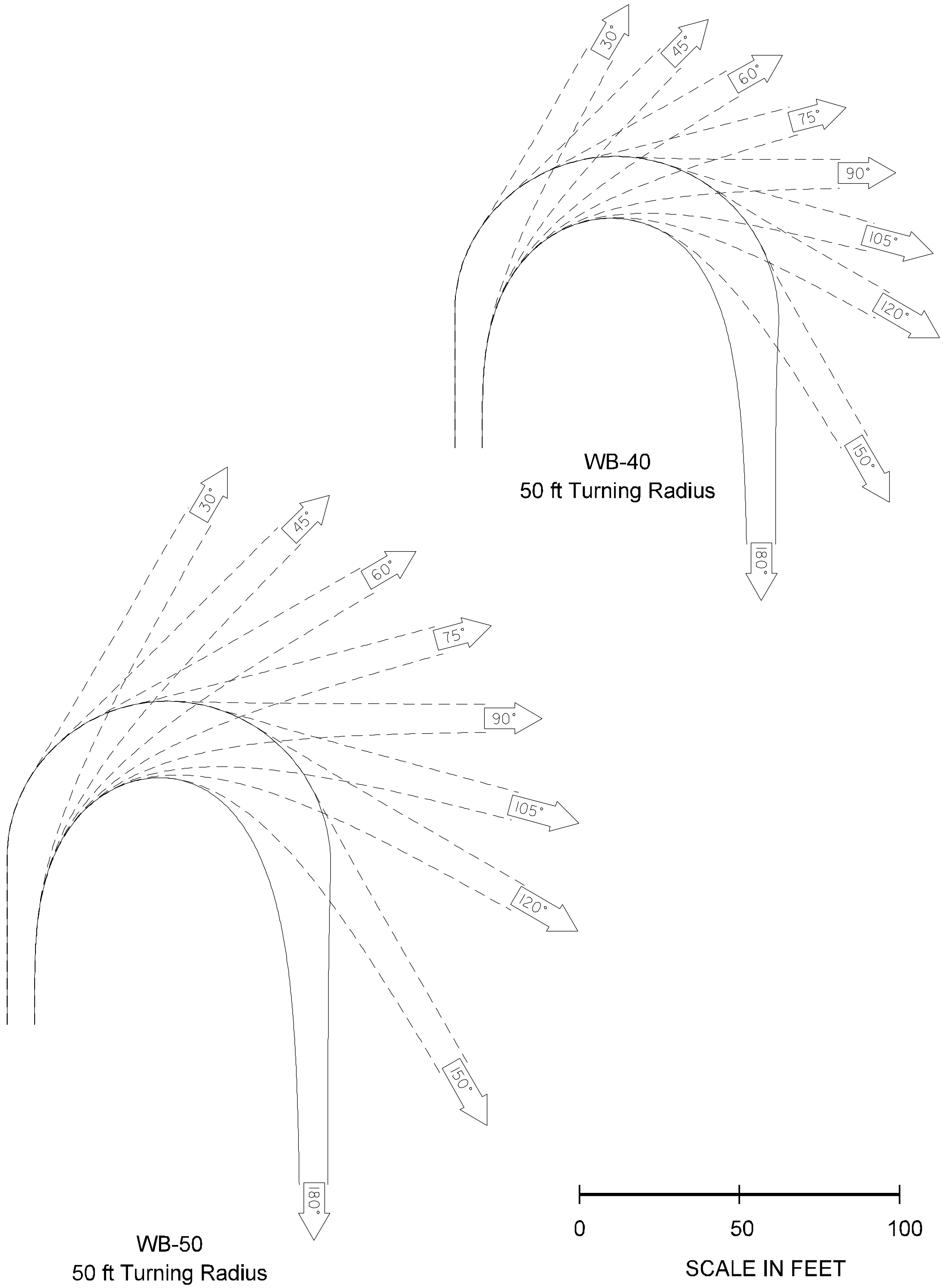
The following documents are to be preserved for future reference in the project file. See Chapter 330.

- ☐ Traffic analyses
- ☐ Accident studies
- ☐ Split tee intersection evaluation
- ☐ Design vehicle selection justifications
- ☐ Justification for encroachment on other lanes
- ☐ Largest vehicle documentation and justification
- ☐ Justification for right-turn corner design modification
- ☐ Left-turn lane justification
- ☐ Two-way left-turn lane justification
- ☐ Right-turn lane justification
- ☐ U-turn documentation
- ☐ Sight distance documentation
- ☐ Approved traffic signal plans
- ☐ Intersection plans and supporting information

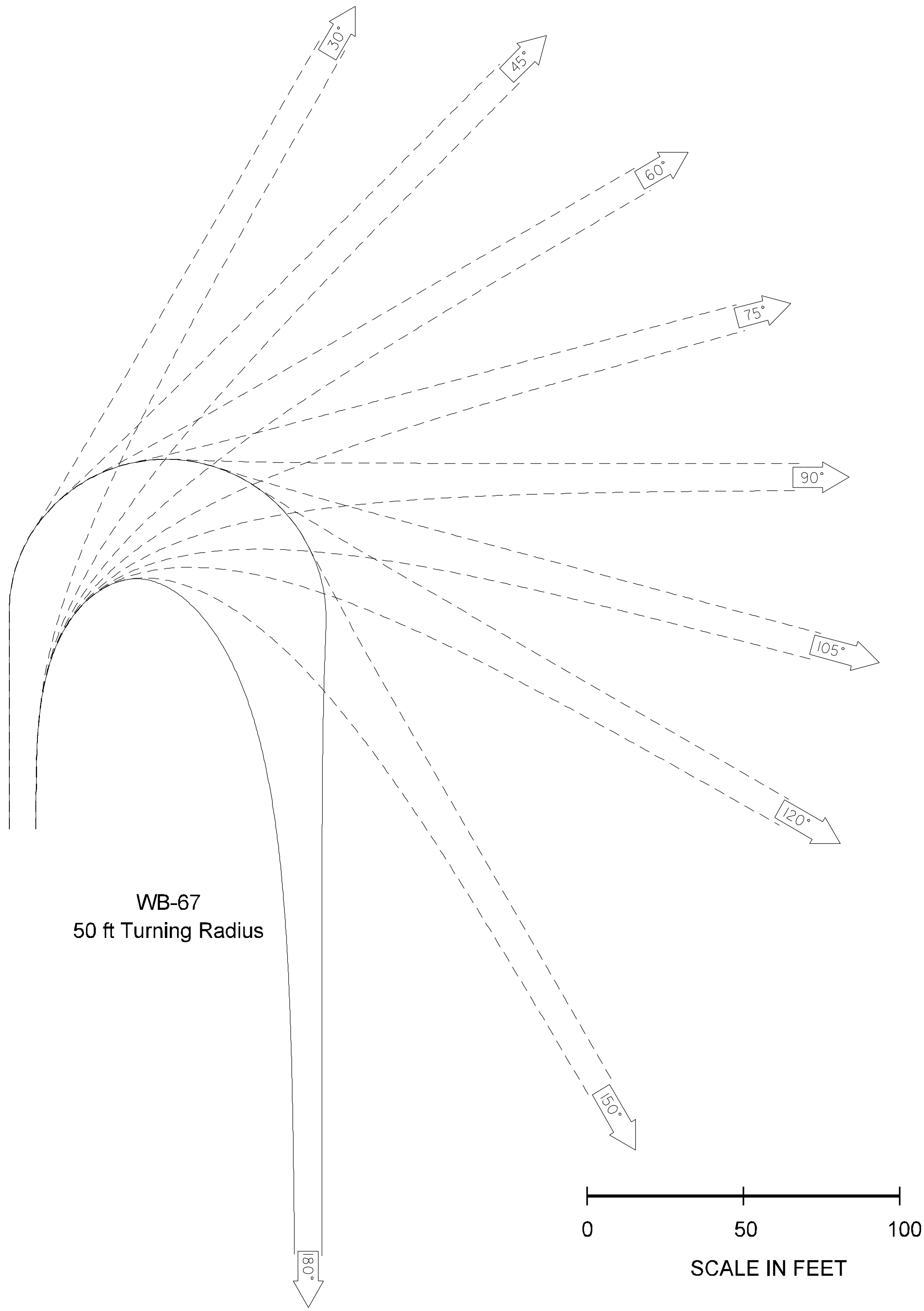


Turning Path Template

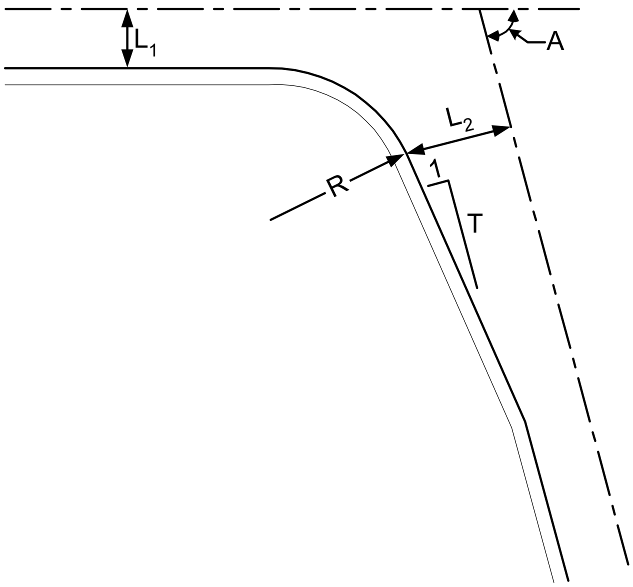
Figure 910-7a



Turning Path Template
Figure 910-7b



Turning Path Template
Figure 910-7c



L_1 = Minimum width of the lane that the vehicle is turning from.

L_2 = Minimum width of the roadway that the vehicle is turning into.

R = Radius to the edge of traveled way.

T = Taper rate (length per unit of width of widening)

A = Delta angle of the turning vehicle

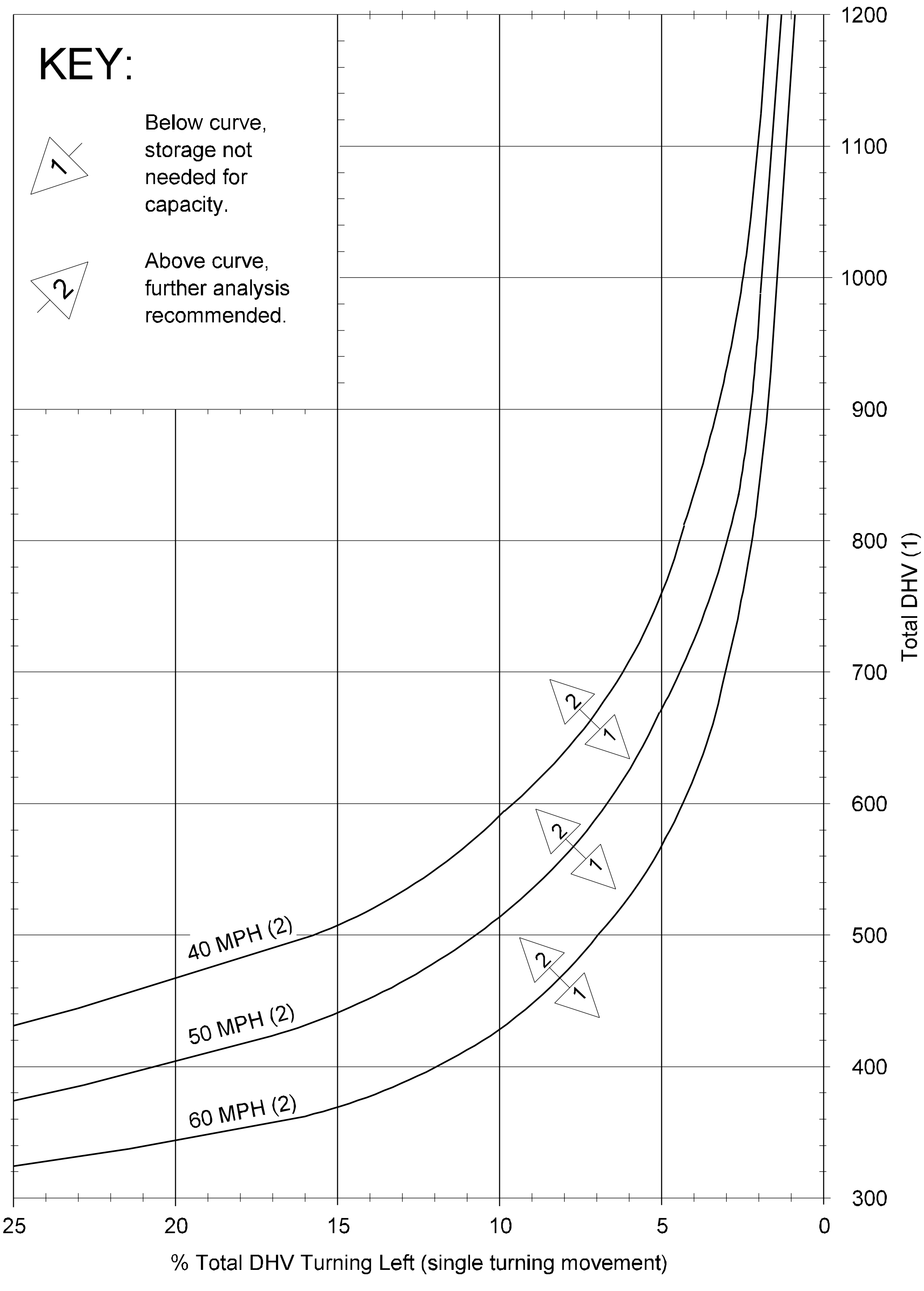
Vehicle	A	R	L_1	L_2(1)	T(2)	Vehicle	A	R	L_1	L_2(1)	T(2)
WB-67	60	85	11	22	7	WB-40	60	55	11	15	7.5
	75	75	11	21	8		75	55	11	15	7.5
	90	70	11	21	8		90	55	11	14	7.5
	105	55	11	24	7		105	45	11	16	7.5
	120	50	11	24	7		120	45	11	15	7.5
WB-50	60	55	11	19	6	SU	All	50	11	11	
	75	55	11	18	6	P	All	35	11	11	
	90	55	11	17	6						
	105	50	11	17	6						
	120	45	11	18	6						

(1) At signalized intersections, include all lanes of the exit leg.

(2) When widening is required to obtain the given values of L_1 or L_2 and no taper rate (T) is given, widen at 25:1.

(3) All distances given in feet and angles in degrees

Right-Turn Corner
Figure 910-8

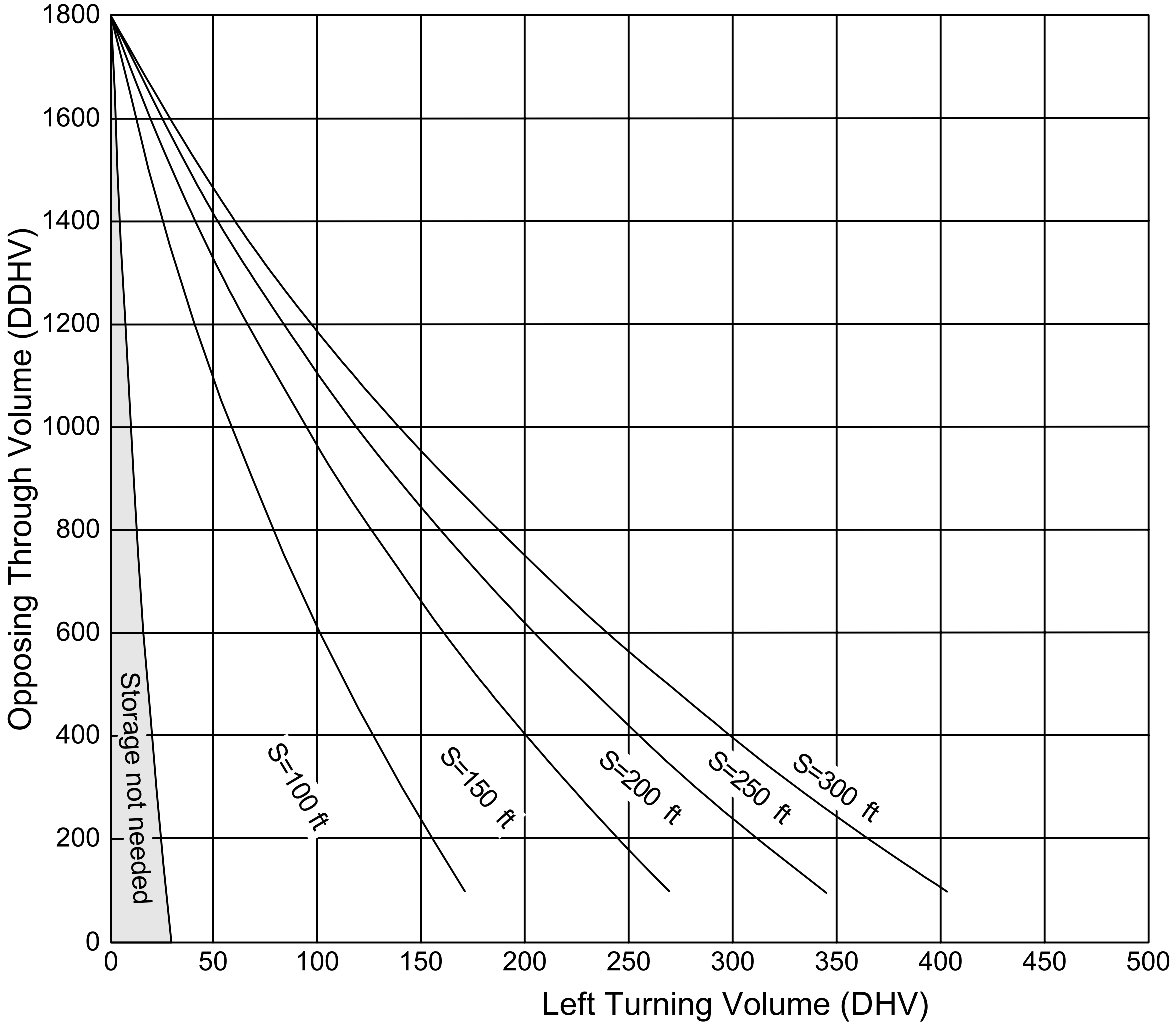


(1) DHV is total volume from both directions.

(2) Speeds are posted speeds.

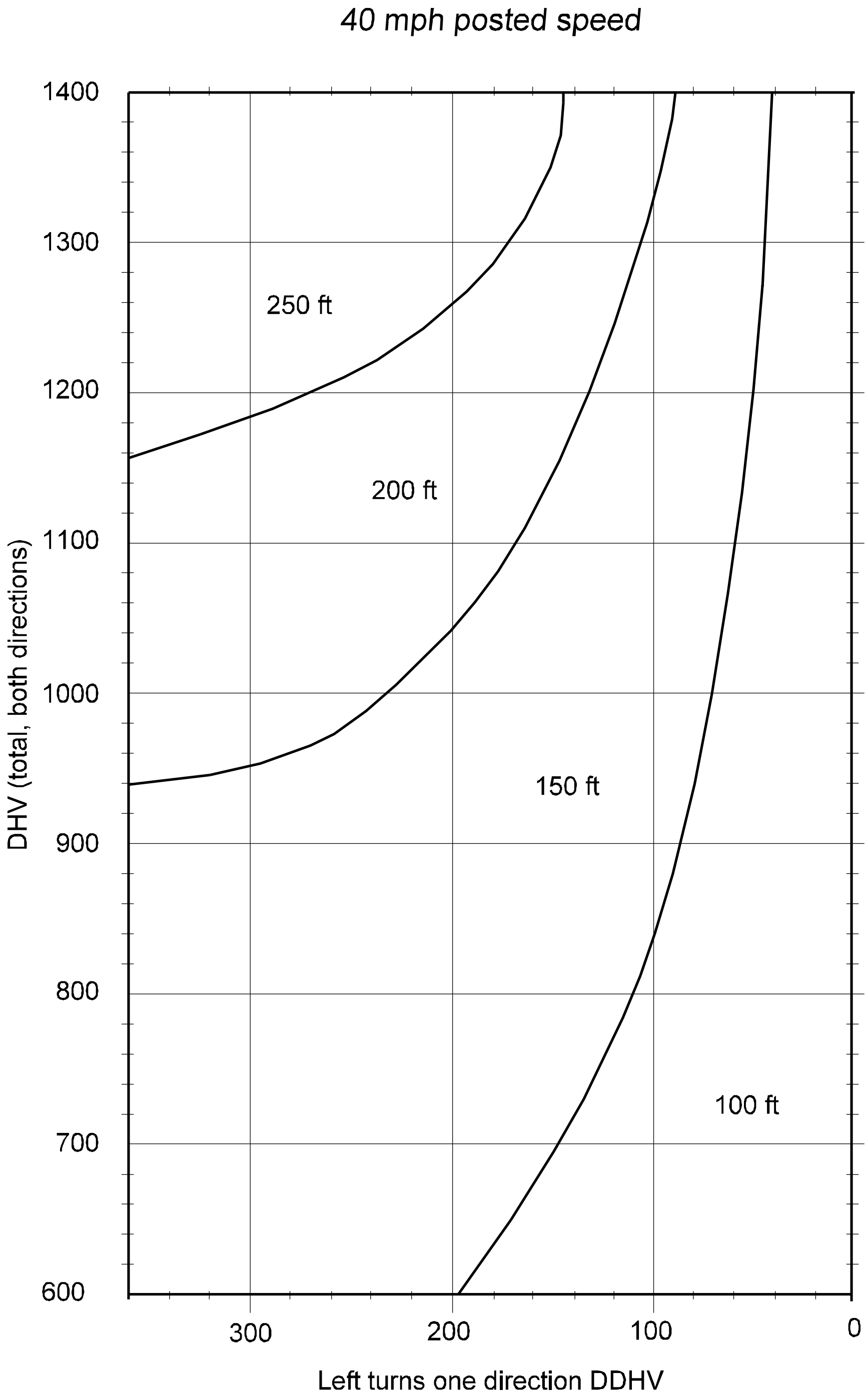
Left-Turn Storage Guidelines <u>(Two-Lane, Unsignalized)</u>

Figure 910-<u>9a</u>

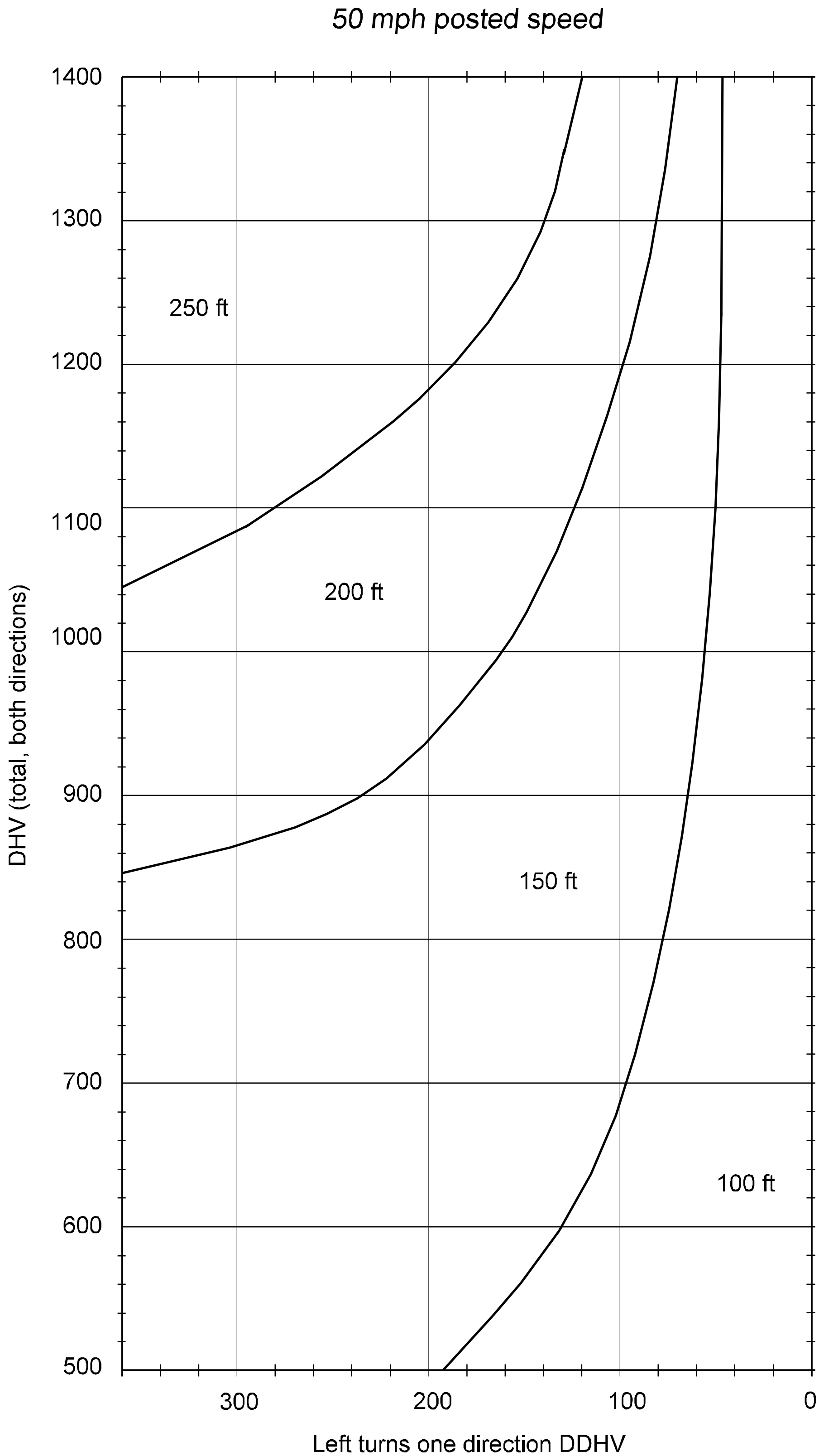


S = Left-Turn storage length

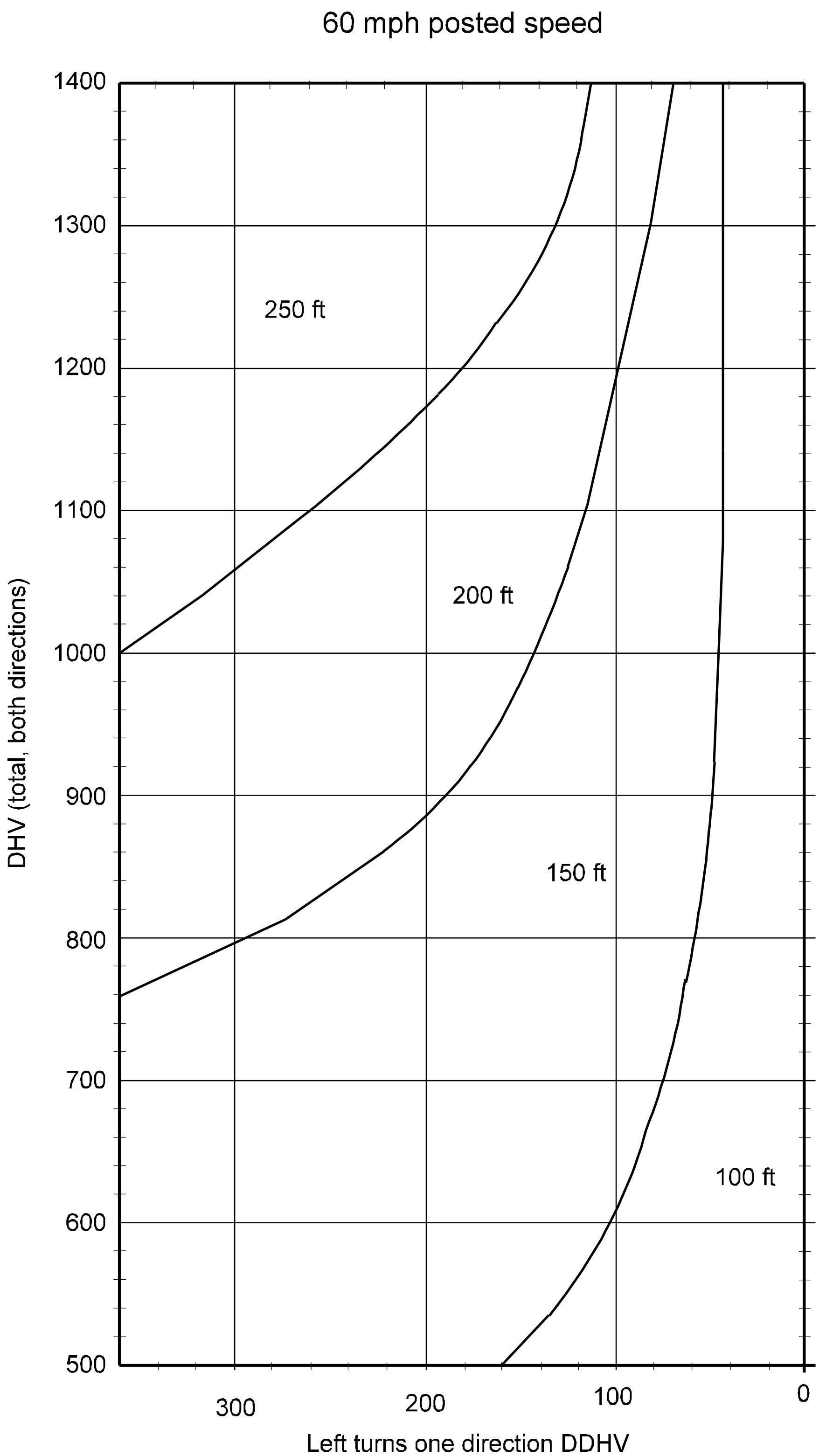
Left-Turn Storage Guidelines (Four-Lane, Unsignalized)
Figure 910-9b



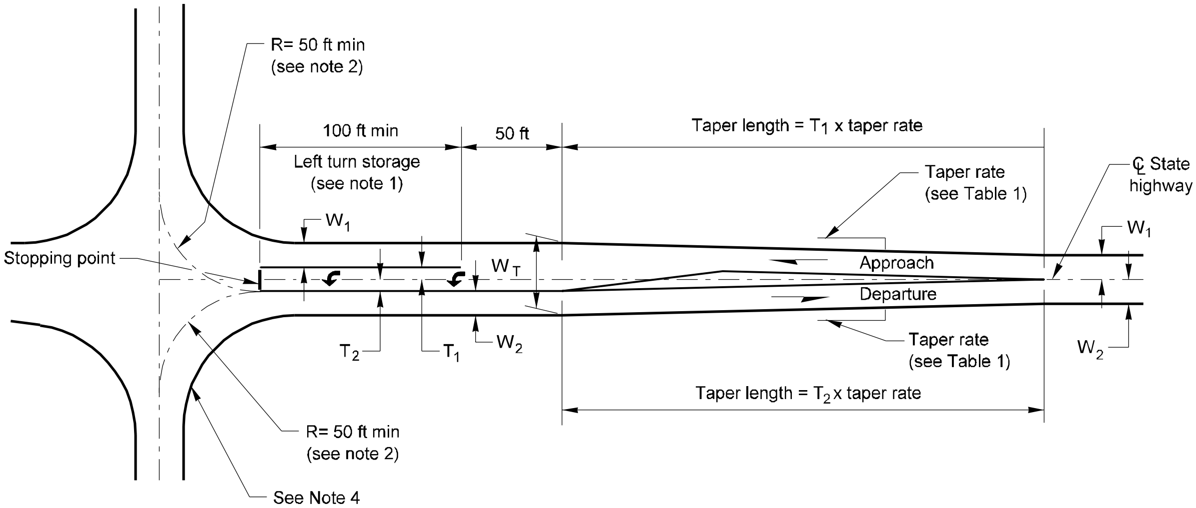
Left-Turn Storage Length <u>(Two-Lane, Unsignalized)</u>
Figure 910-<u>10</u>a



Left-Turn Storage Length (Two-Lane, Unsignalized)
Figure 910-10b



Left-Turn Storage Length (Two-Lane, Unsignalized)
Figure 910-10c



Notes:

(1) The minimum width of the left-turn storage lane (T_1+T_2) is 11 ft. The desirable width is 12 ft. For left-turn storage length, see Figures 910-9b for 4-lane roadways or 10a through 10c for 2-lane roadways.

(2) Use templates for WB-67 design vehicles.

(3) See Standard Plans and MUTCD for pavement marking details.

(4) See Figure 910-8 for right-turn corner design.

W_1 = Approaching through lane.

W_2 = Departing lane.

T_1 = Width of left-turn lane on approach side of center line.

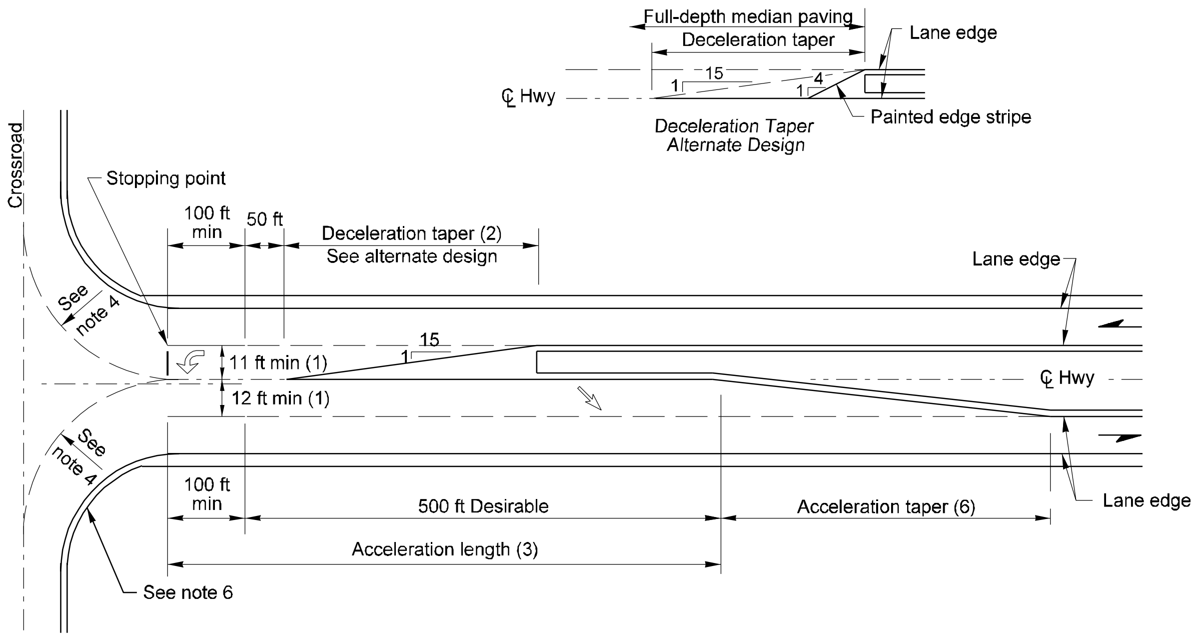
T_2 = Width of left-turn lane on departure side of center line.

W_T = Total width of channelization (W_1+W_2+T_1+T_2)

Posted Speed	Acceleration Taper Rate
55 mph	55:1
50 mph	50:1
45 mph	45:1
40 mph	40:1
35 mph	35:1
30 mph	30:1
25 mph	25:1

Table 1

Median **Channelization (Widening)**
Figure 910-11a



Notes:

(1) Lane widths of 13 ft are desirable for both the left-turn storage lane and the median acceleration lane.

(2) For increased storage capacity, consider the left-turn deceleration taper alternate design.

(3) The minimum total length of the median acceleration lane is shown in Figure 910-15.

(4) R = 50 ft min; use templates for WB-67 design vehicles.

(5) See Figure 910-8 for right-turn corner design.

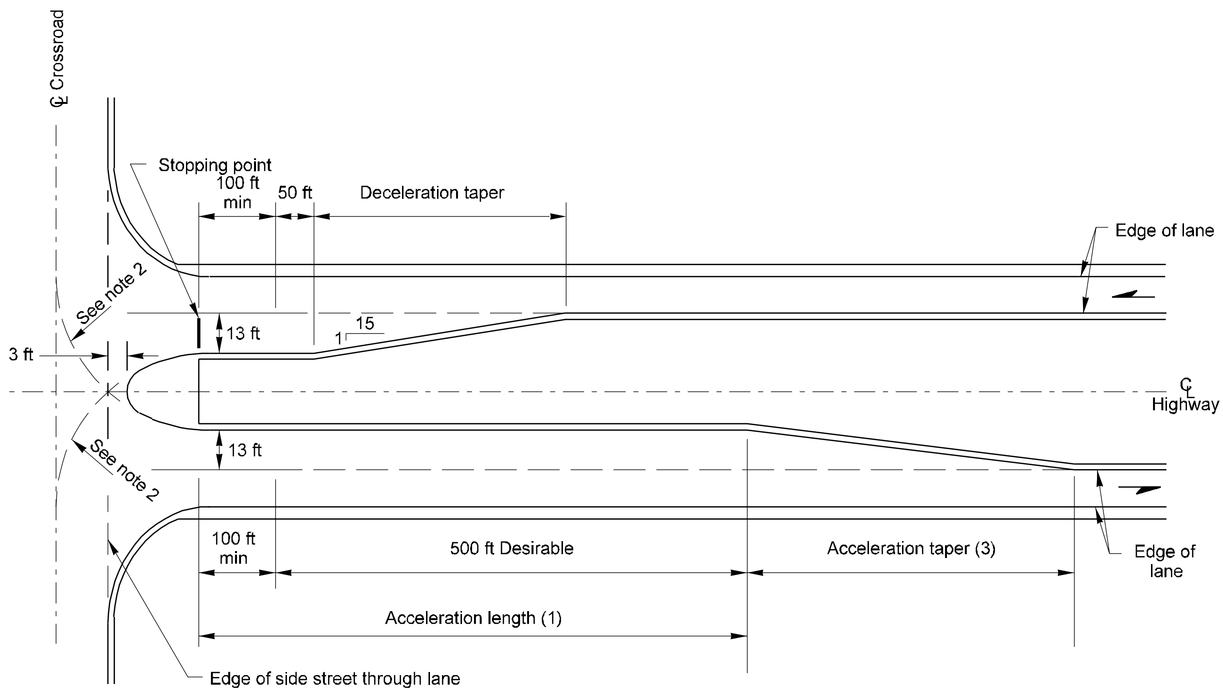
(6) See Table 2 for acceleration tape rate.

(7) See Standard Plans and MUTCD for pavement marking details.

Posted Speed	Acceleration Taper Rate
55 mph	55:1
50 mph	50:1
45 mph	45:1
40 mph	27:1
35 mph	21:1
30 mph	15:1
25 mph	11:1

Table 2

Median Channelization — Median Width 23 ft to 26 ft
Figure 910-11b



Notes:

(1) The minimum length of the median acceleration lane is shown in Figure 910-15.

(2) R = 50 ft min. Use templates for WB-67 design vehicles.

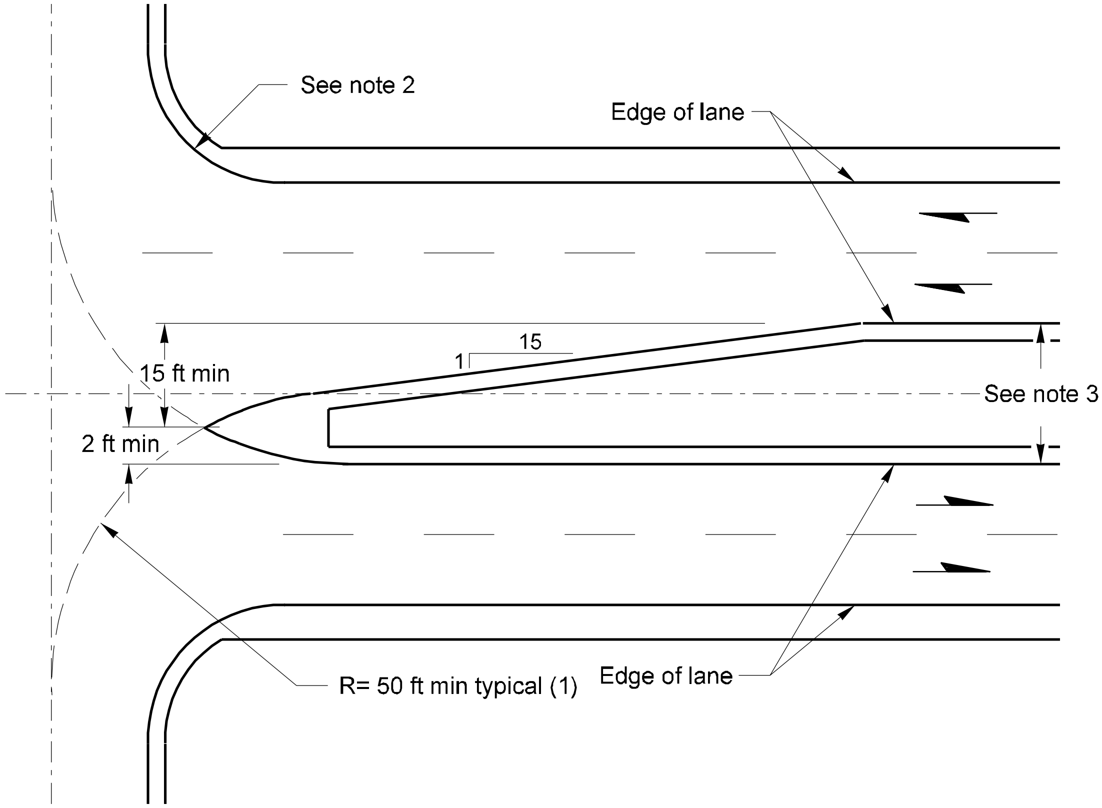
(3) See Table 2 Figure 910-11b for acceleration tape rate.

(4) See Figure 910-8 for right-turn corner design.

(5) See Standard Plans and MUTCD for pavement marking details.

Median Channelization — Median Width of More Than 26 ft

Figure 910-11c



Notes:

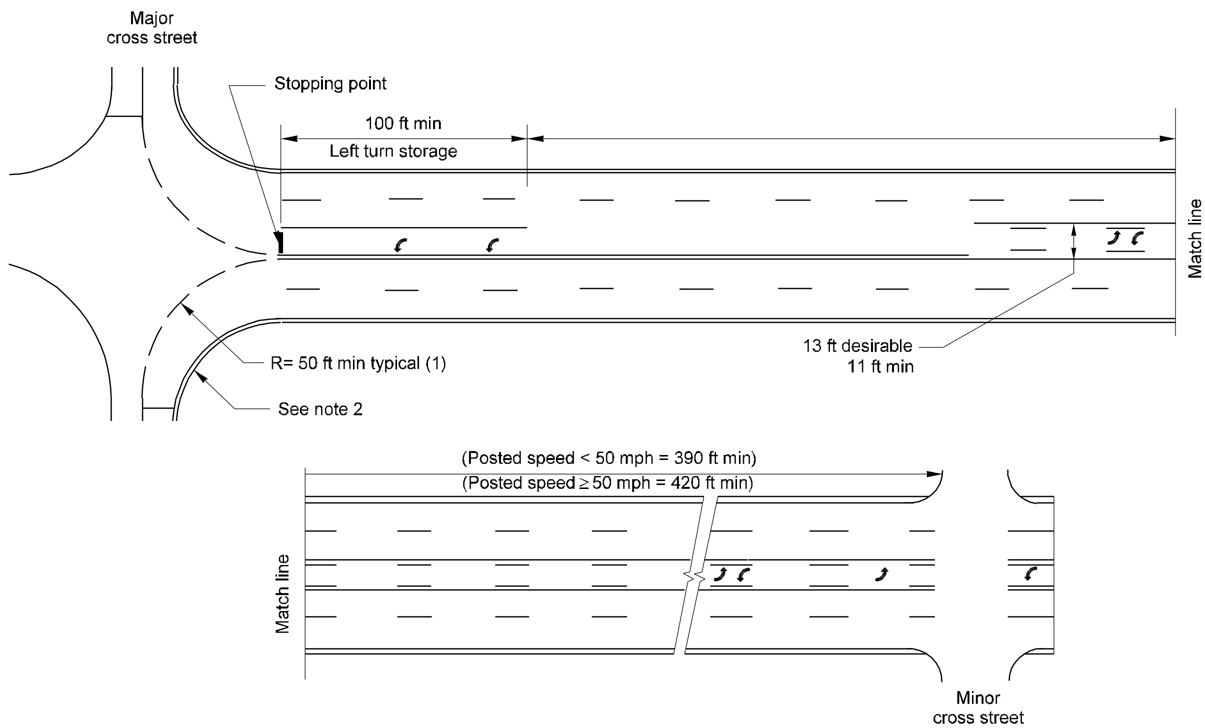
(1) Use templates for WB-67 design vehicle.

(2) See Figure 910-8 for right-turn corner design.

(3) For median width 17 ft or more. For median width less than 17 ft, widen to 17 ft or use Figure 910-11b without median acceleration lane.

(4) See Standard Plans and MUTCD for pavement marking details.

Median Channelization (Minor Intersection)
Figure 910-11d



Notes:

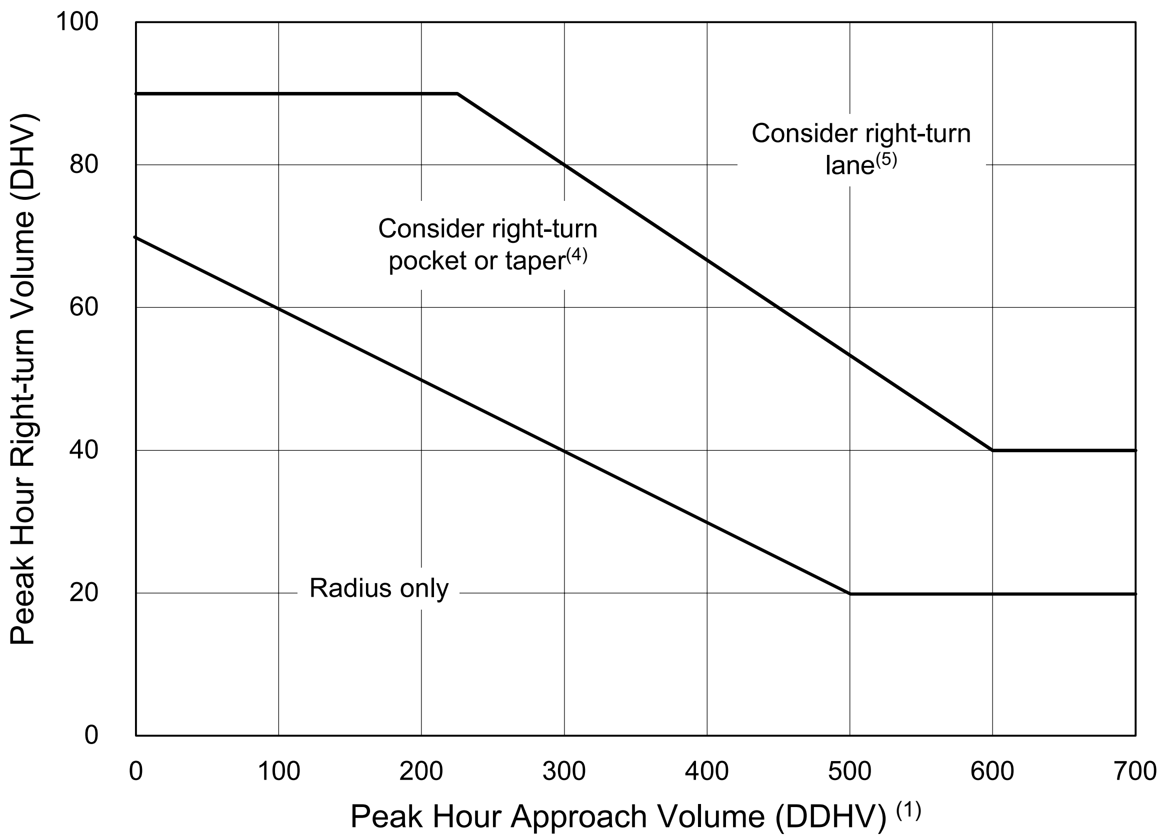
(1) Use templates for WB-67 design vehicle.

(2) See Figure 910-8 for right-turn corner design.

(3) See the Standard Plans and the MUTCD for pavement marking details and signing criteria.

Median Channelization (Two-Way Left-Turn Lane)

Figure 910-11e



(1) For two-lane highways, use the peak hour DDHV (through + right-turn).

For multilane, high speed highways (posted speed 45 mph or above), use the right-lane peak hour approach volume (through + right-turn).

For multilane, low speed highways (posted speed less than 45 mph), there is no traffic volume right-turn lane or taper requirement.

(2) When all three of the following conditions are met, reduce the right-turn DDHV by 20.

- The posted speed is 45 mph or less
- The right-turn volume is greater than 40 VPH.
- The peak hour approach volume (DDHV) is less than 300 VPH.

(3) See Figure 910-8 for right-turn corner design.

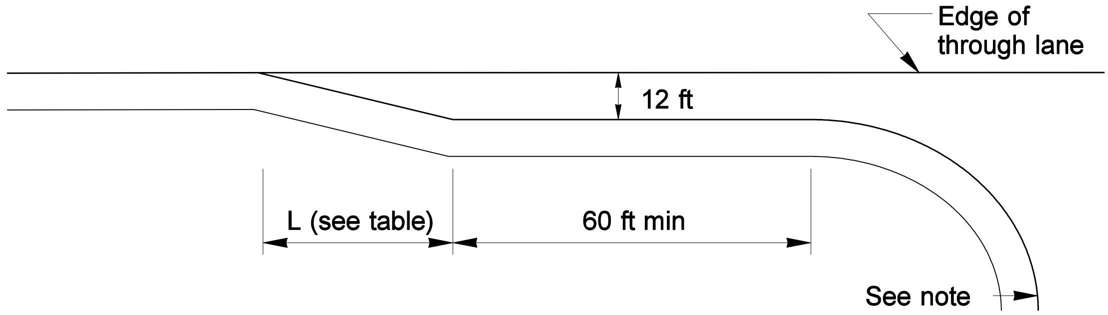
(4) See Figure 910-13 for right-turn pocket or taper design.

(5) See Figure 910-14 for right-turn lane design.

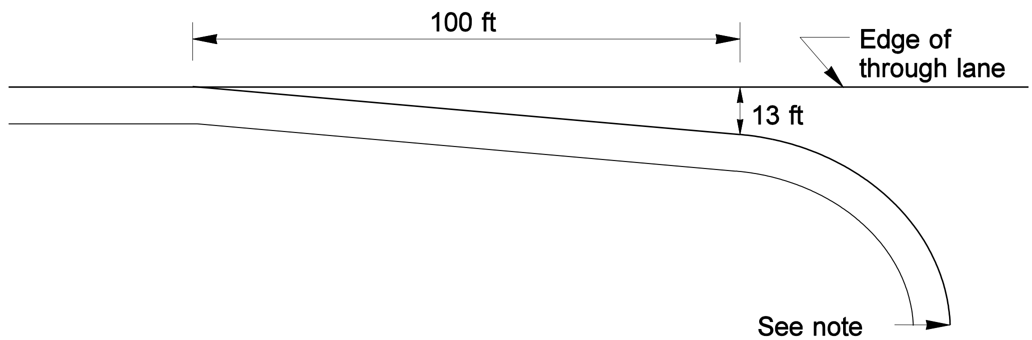
(6) For additional guidance, see 910.07(2) in the text.

Right-Turn Lane Guidelines[6]

Figure 910-12



Right-Turn Pocket

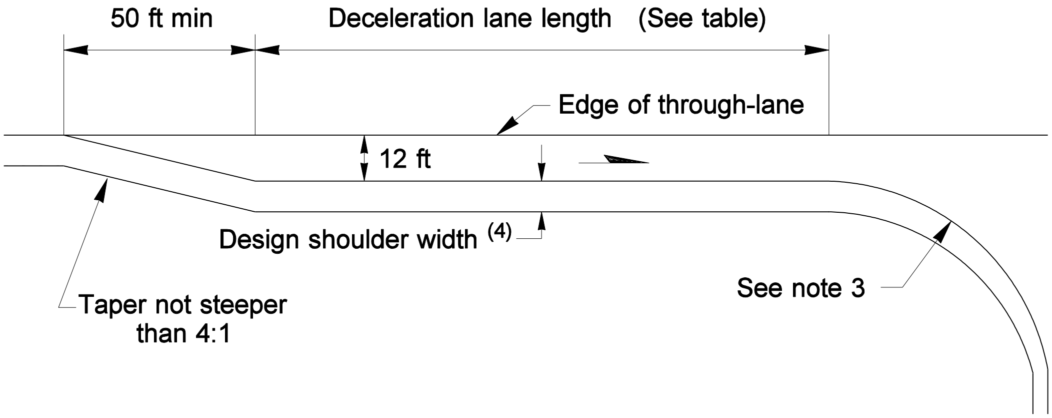


Right-Turn Taper

Posted speed limit	L
Below 40 mph	40 ft
40 mph or above	100 ft

Note: See Figure 910-8 for right-turn corner design.

Right-Turn Pocket and Right-Turn Taper
Figure 910-13



Highway Design Speed (mph)	Turning Roadway design speed (mph)		
	Stop(1)	15	20
30	235	185(2)	160(2)
40	335	305	275
50	425	390	365
60	530	490	470
70	605	580	565

Minimum Deceleration Lane Length (ft)

Grade	Upgrade	Downgrade
3% to less than 5%	0.9	1.2
5% or more	0.8	1.35

Adjustment Multiplier for Grades 3% or Greater

Notes:

(1) For use when the turning traffic is likely to stop before completing the turn. (For example, where pedestrians are present.)

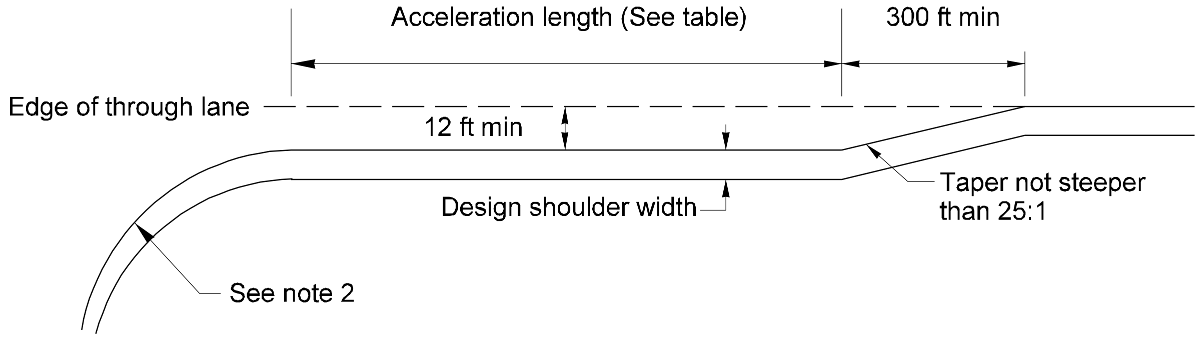
(2) When adjusting for grade, do not reduce the deceleration lane to less than 150 ft.

(3) See Figure 910-8 for right-turn corner design.

(4) May be reduced to 4 ft, see 910.07 (2) in the text.

Right-Turn Lane

Figure 910-14



Highway Design Speed (mph)	Turning Roadway Design Speed (mph)		
	Stop	15	20
30	180		
40	395	320	270
50	640	560	510
60	1115	1015	955
70	1495	1415	1350

Minimum Acceleration Lane Length (ft)

Highway Design Speed (mph)	% Grade	Upgrade	Downgrade
40	3% to less than 5%	1.3	0.7
50		1.3	0.65
60		1.4	0.6
70		1.5	0.6
40	5% or more	1.5	0.6
50		1.5	0.55
60		1.7	0.5
70		2.0	0.5

Adjustment Multiplier for Grades 3% or Greater

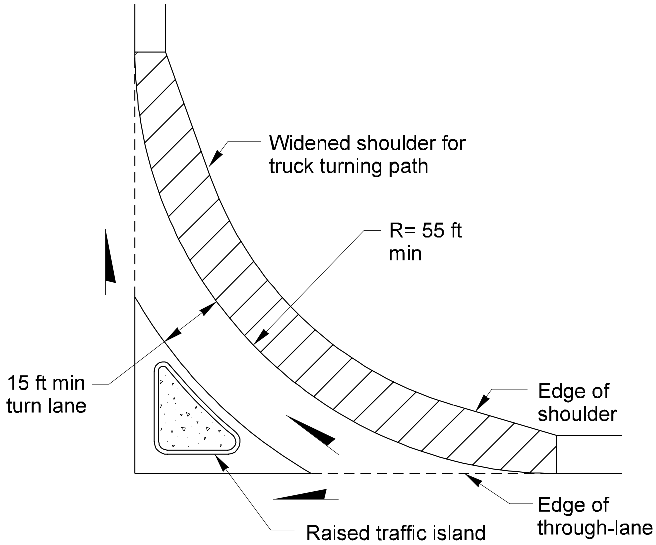
Notes:

(1) The minimum acceleration lane length for freeways and expressways is 900 ft.

(2) See Figure 910-8 for right-turn corner design.

Acceleration Lane

Figure 910-15



Small Island Design

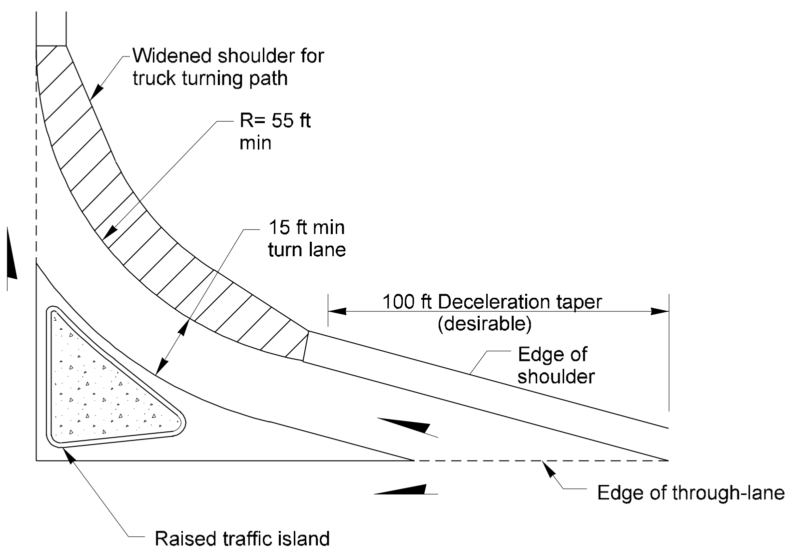
Notes:

(1) Widen shoulders when adequate right-turn radii or roadway width cannot be provided for large trucks. Design widened shoulder pavement the same depth as the right-turn lane.

(2) Use the truck turning path templates for the design vehicle and a minimum of 2 ft clearance between the wheel paths and the face of a curb or edge of shoulder to determine the width of the widened shoulder.

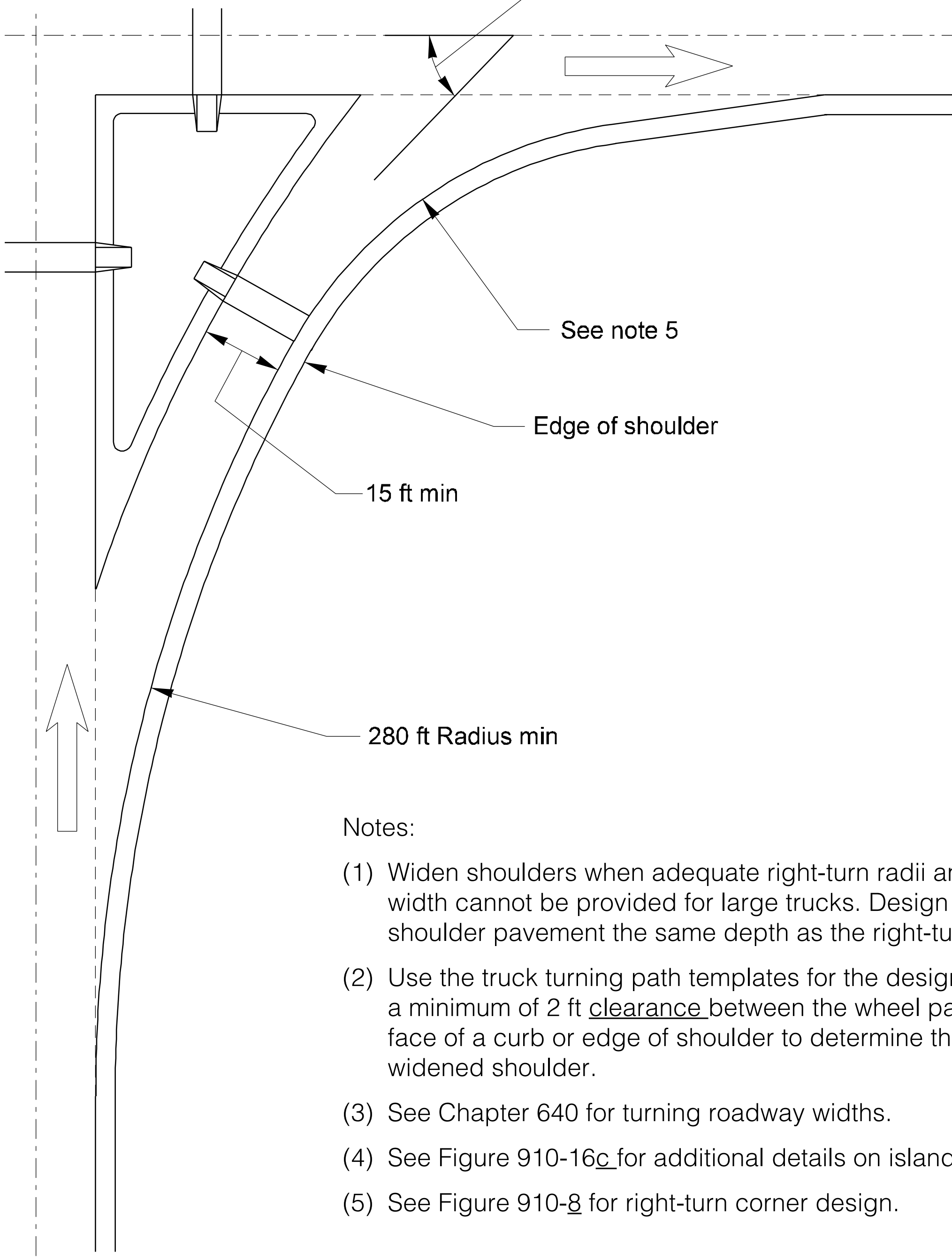
(3) See Chapter 640 for turning roadway widths.

(4) See Figure 910-16c for additional details on island placement



Large Island Design

Traffic Island Designs
Figure 910-16a



Notes:

(1) Widen shoulders when adequate right-turn radii and roadway width cannot be provided for large trucks. Design widened shoulder pavement the same depth as the right-turn lane.

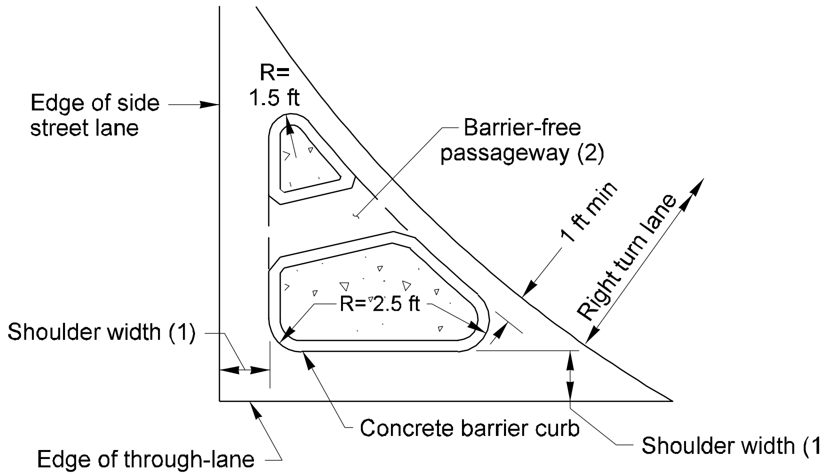
(2) Use the truck turning path templates for the design vehicle and a minimum of 2 ft clearance between the wheel paths and the face of a curb or edge of shoulder to determine the width of the widened shoulder.

(3) See Chapter 640 for turning roadway widths.

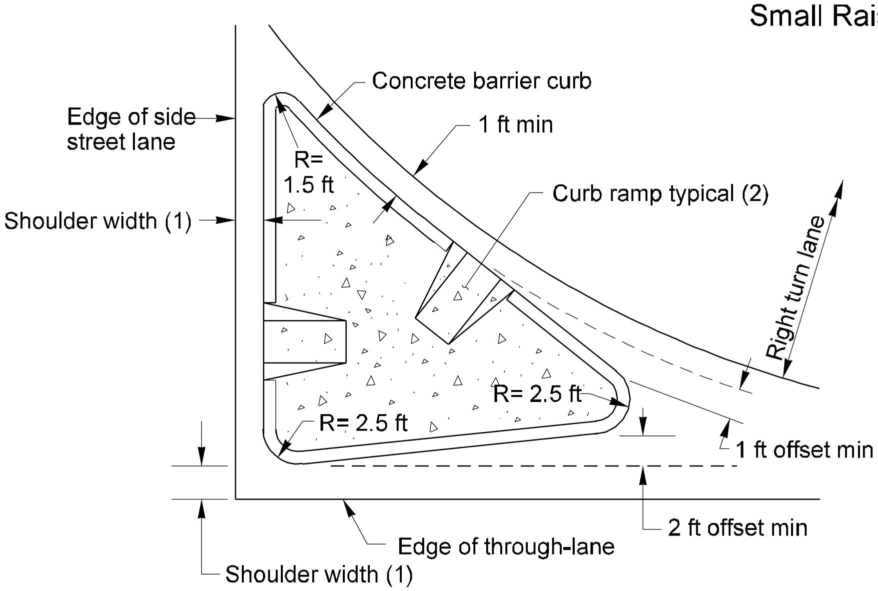
(4) See Figure 910-16c for additional details on island placement

(5) See Figure 910-8 for right-turn corner design.

Traffic Island Designs (Compound Curve)
Figure 910-16b



Small Raised Traffic Island



Large Raised Traffic Island

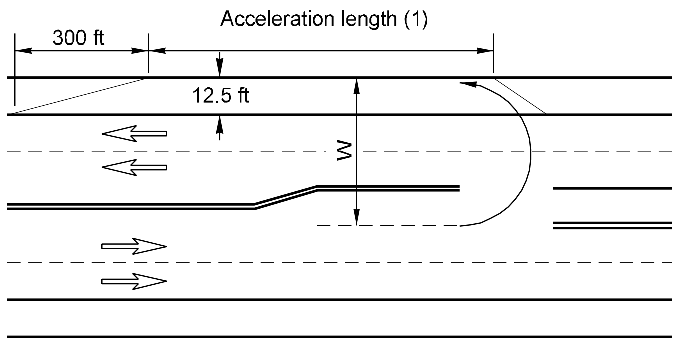
Notes:

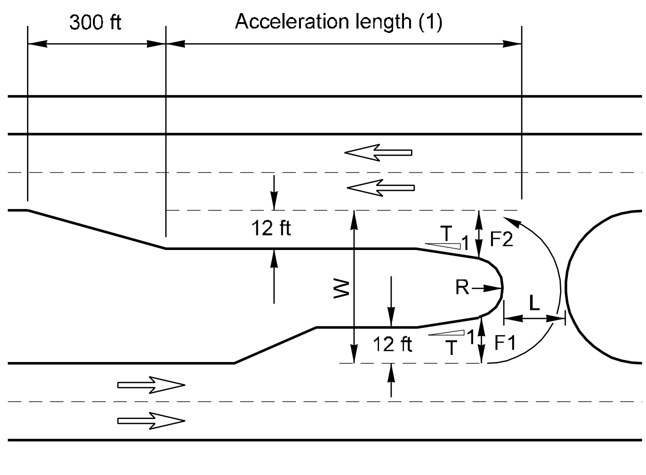
(1) See Chapter 440 for minimum shoulder width. See the text for additional information on shoulders at islands.

(2) Provide barrier-free passageways or curb ramps when required, see Chapter 1025.

Traffic Island Designs

Figure 910-16c





Vehicle	W	R	L	F1	F2	T
P	52	14	14	12	12	—
SU	87	30	20	13	15	10:1
BUS	87	28	23	14	18	10:1
WB-40	84	25	27	15	20	6:1
WB-50	94	26	31	16	25	6:1
WB-67	94	22	49	15	35	6:1
MH	84	27	20	15	16	10:1
P/T	52	11	13	12	18	6:1
MH/B	103	36	22	15	16	10:1

U-Turn Design Dimensions (ft)

Notes:

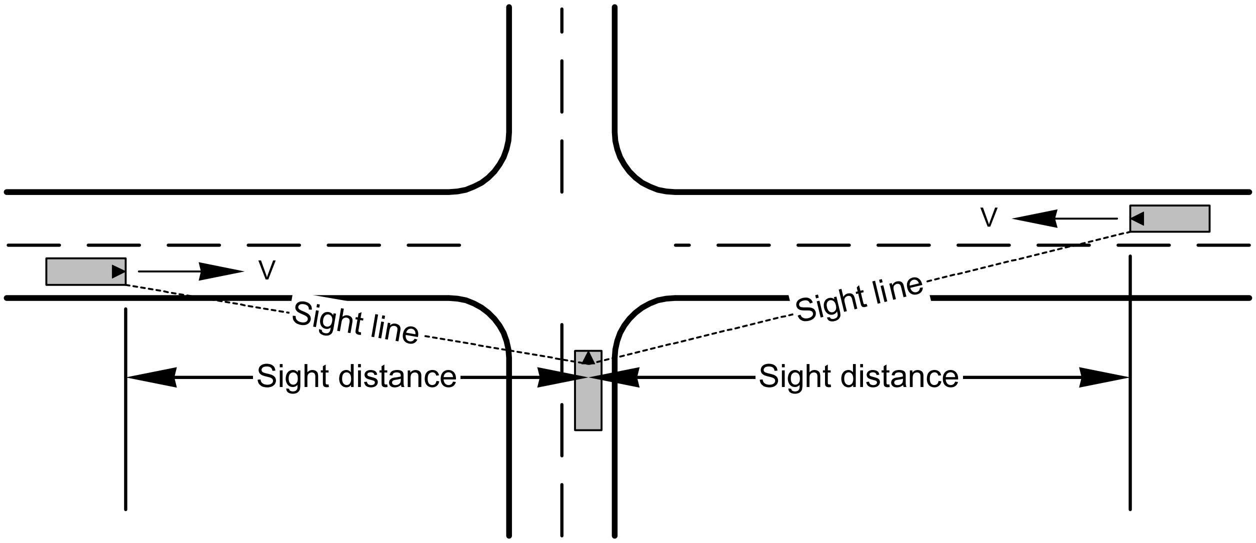
(1) The minimum length of the median acceleration lane is shown in Figure 910-15.

(2) All dimensions in feet.

(3) When U-turn uses the shoulder, provide 12.5 ft shoulder width and shoulder pavement designed to the same depth as the through lanes for the acceleration length and taper.

U-Turn Locations

Figure 910-17



$SD = 1.47Vt_g$
Where:
SD = Sight Distance (ft)
V = Design speed of the through roadway (mph)
t_g = Time gap for the minor roadway traffic to enter or cross the through roadway (s)

Intersection Sight Distance Equation
Table 1

Design Vehicle	Time Gap (t_g) in seconds
Passenger car (P)	9.5
Single unit trucks and buses (SU & BUS)	11.5
Combination trucks (WB-40, WB-50, & WB-67)	13.5
Note: Values are for a stopped vehicle to turn left or right onto a two-lane two-way roadway with no median and grades 3% or less. Includes 2 sec for perception/reaction time.	

Intersection Sight Distance
Gap Times (t_g)
Table 2

The t_g values listed in Table 2 require the following adjustments:

Crossing maneuvers:

All vehicles subtract 1.0 s

Multilane roadways:

Left-turns, for each lane in excess of one to be crossed and for medians wider than 4 ft:

Passenger cars add 0.5 s
All trucks and buses add 0.7 s

Crossing maneuvers, for each lane in excess of two to be crossed and for medians wider than 4 ft:

Passenger cars add 0.5 s
All trucks and buses add 0.7 s

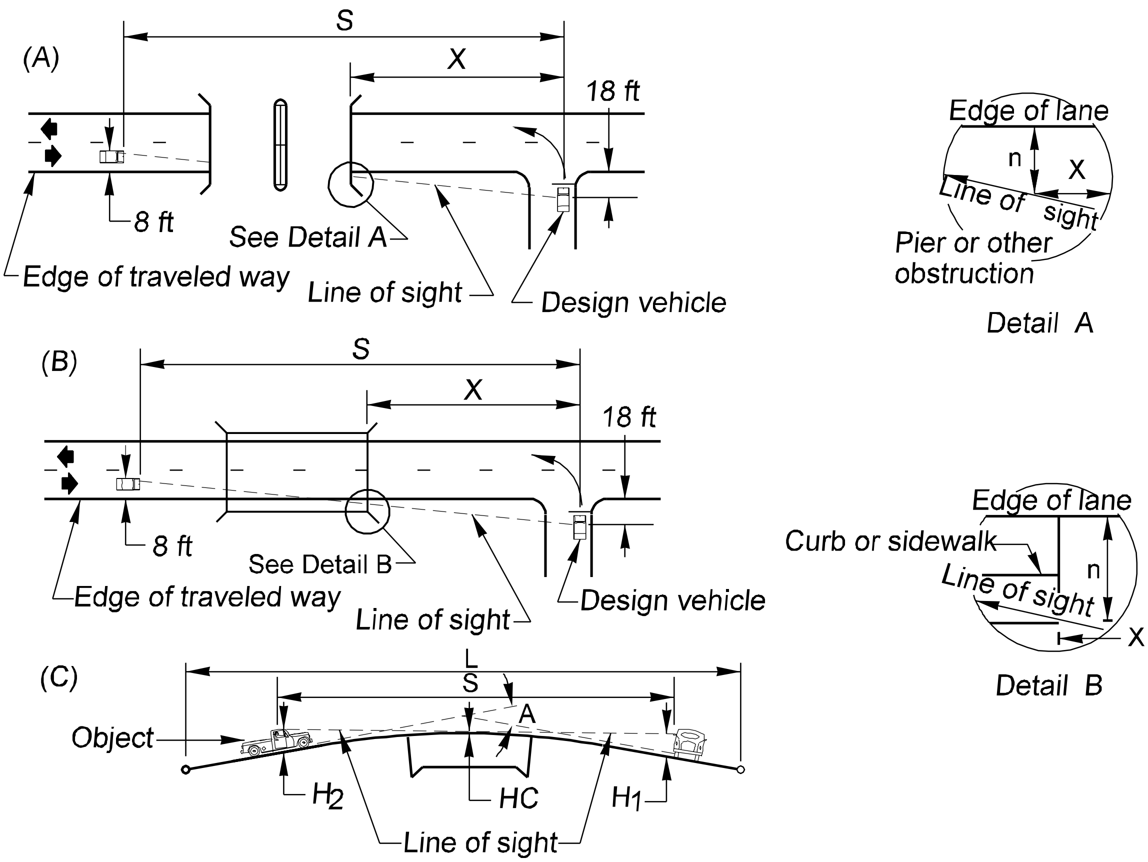
Note: Where medians are wide enough to store the design vehicle, determine the sight distance as two maneuvers.

Crossroad grade greater than 3%:

All movements upgrade, for each percent that exceeds 3%:

All vehicles add 0.2 s

Sight Distance for Grade Intersection With Stop Control
Figure 910-18a



For bridge pier or bridge rail:

$$S = \frac{26(x)}{18 - n}$$

Where:

S = Available sight distance (ft)

n = Offset from sight obstruction to edge of lane (ft)

X = Distance from center line of lane to sight obstruction (ft)

For crest vertical curve over a curb where S<L:

$$S = \sqrt{\frac{100L\left[\sqrt{2(H_1 - HC)} + \sqrt{2(H_2 - HC)}\right]^2}{A}}$$

$$L = \frac{AS^2}{100\left[\sqrt{2(H_1 - HC)} + \sqrt{2(H_2 - HC)}\right]^2}$$

Where:

S = Available sight distance (ft)

H_1 = Eye height (3.5 ft)

H_2 = Object height (4.25 ft)

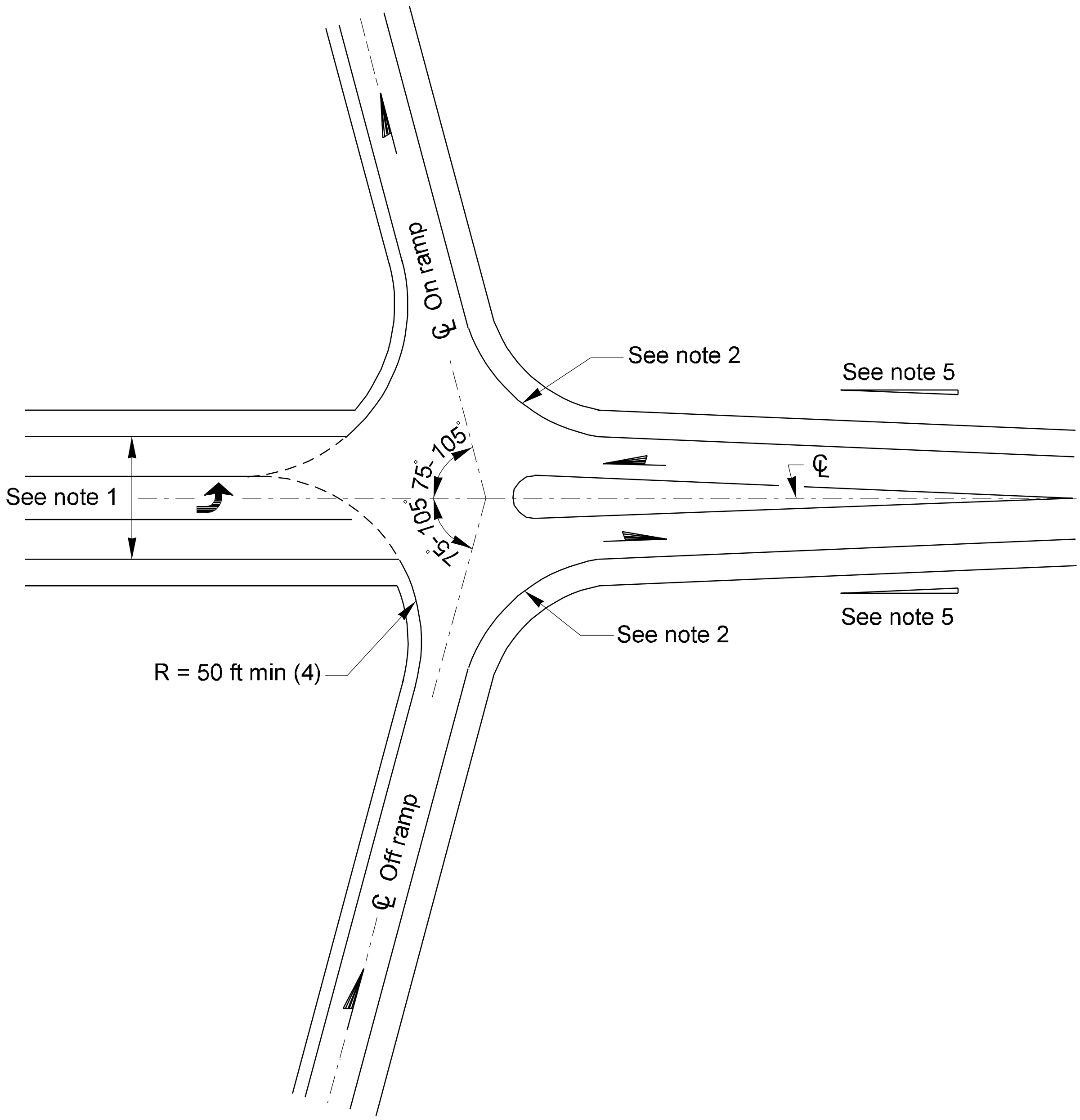
HC = Curb height (ft)

L = Vertical curve length (ft)

A = Algebraic difference in grades (%)

Sight Distance at Intersections

Figure 910-18b



Notes:

(1) 12 ft through-lanes and 13 ft left-turn lane desirable.

(2) For right-turn corner design see Figure 910-8.

(3) Intersections may be designed individually.

(4) Use templates for the WB-67 design vehicle.

(5) See Figure 910-11a, Table 1 for taper rates.

Interchange Ramp Details

Figure 910-19